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IRON.

This is the most extensive, and by far the most valuable manufacture of this, or indeed of any country: for beside its intrinsic importance, the perfection of almost every other manufacture depends upon that of Iron.

Important as it is, I know of none so long practised and so little understood. Almost all the principal publications relating to it, I have at one time or other had occasion to consult; but little as I have seen of the practice, I am fully persuaded, that no reading will compensate for want of opportunity of observing the actual state of the manufacture leisurely and patiently in all its stages. However, I am certain that it will be a work of utility, to digest and condense the principal facts and observations that I can find registered in the publications relating to this subject. Those who desire more minute information from writers, will have to consult,

The detail of the Swedish practice in folio with many plates by the *Baron Emanuel Swedenborg*. I have not met with this laborious and important work, (which I formerly perused with much interest) in this country. Nor have I found here,

Rinman's Historia ferri; a very good book, which is not yet translated that I know of, at least into English. It is translated into German. This was first published in 1782. 1772 the same author (Sueno Rinman) published his Introduction to the art of improving the manufactory of Iron and Steel. In 1789 his large Dictionary of mining. In 1784 and in 1798 and 1800 he published his System of mechanics with their application to mining in conjunction with Erick Nordwall. These works, of which I have seen none but the Historia ferri, are regarded as stock books on the subject, and ought to be in every

publick library: especially, as even yet in England, their best steel can only be made out of Swedish iron.

In 1783 I translated for my deceased friend Dr. Ch. Taylor, the Dissertation *or Thesis de Analysi Ferri*, of J. Gadolin, published by Bergman, which first gave to the public, accurate experiments on the different products of iron and steel when treated in the moist way.

Horne's essay on iron and steel, 12mo. is a book well spoken of, which I have never seen.

Reaumur's small treatise on the conversion of iron into steel: of which there is an English translation: but the observations and theory, are for the most part superceded by the more accurate knowledge of the present day.

The works I have actually consulted for the present occasion, are

The mineralogical treatise of *Schlutter*, by Hellot, in 3 vols. quarto, of which there are two copies in Philadelphia.

The mineralogical travels of *Mr. Jars*, in 3 vols. quarto.

The series of Essays of *David Mushet, Esq.* of the Clyde iron works.

Bergman's dissertation on the white ores of iron, and the essay *de analysi ferri.*

Tilloch's Philosophical magazine.

The specifications of *Mr. Cort*, and *Mr. John Wilkinson*, in the Repertory of arts, and *Dr. Beddoes's* account of Mr. Cort's process.

The essays of *Dr. Collier* on the steel furnace in the Manchester Transactions: and of *Mr. Varley*, in Dr. Tilloch's Philosophical magazine.

The detached essays on steel in Nicholson's Journal: and

The well-written articles in *Aikins's* Dictionary, and in *Ree's* new Encyclopædia. Giving however my own view of the subject, and adding occasionally my own remarks where I feel myself entitled to offer them.

There are few chemists in this country among manufacturers, and I shall therefore endeavour to make use of such language, that men who are not skilful chemists may understand me, but some technical expressions I must employ. I do not write for professed chemists, or to instruct practical iron masters, or to transform suddenly a person who is ignorant of the subject, into a skilful founder, or forgeman: but to lay together such observations, as may give some connected ideas to those who are not Iron masters, and lead those who are, to reflect on the views which ought to guide every part of their process, as it comes in succession.

Preliminary observations. I have repeatedly met with persons, who think that nothing more is necessary to render a place valuable for iron works than that there should be plenty of iron ore on it. But, beside this (which ought to be at least a 20 years stock,) it is necessary to enquire, whether there be plenty of wood for charcoal, and at what price a permanent and perpetual supply can be obtained—whether there be plenty of water to furnish at all times the necessary force—whether the situation be convenient to a never failing market for the ware when made—whether it be within reach of water carriage—what other works interfere with it—whether lime-stone be handy if it should be necessary as a flux—at what price per ton the ore and the coal can be delivered at the furnace—and what is the quality of the ore itself. For this purpose, it may be well enough, not merely to get the opinion of some skilful iron master or founder in the first instance, but also to get a loop or two, run in a rough way at a bloomery, out of the ore. When all this is satisfactorily ascertained—when the ore bank, and the woodland is purchased—when the water-force for the blast is secured—the capital to build the purchase on a moderate scale, say 30 feet square on the ground plan; to raise the dam, to dig the race, to lay on

the water; to construct the water wheel, the drums, the out-buildings; to erect cottages for the work people; to furnish teams; to lay at the furnace mouth three months supply of coal, and ore, and lime-stone; to make roads; to pay wages and other current expences for six months before any return of capital is made, will require 10,000 dollars to enable the iron master to go on smoothly, and without making sacrifices. A man of experience in the business *may* begin with something less: but the experiment is rendered hazardous, requiring incessant diligence; and many accidents that though not foreseen, ought to be counted upon, may defeat the undertaking: moreover, to every calculation of probable cost, at least ten per cent ought to be added for the article of contingent expences, to which every new undertaking is liable.

It is not common in England to erect iron works without making a bloomery, a slitting mill, and a rolling mill, parts of the establishment. It ought to be so every where, but it is seldom so in this country.

In England very few iron works depend upon a water force: they are worked by steam engines: in this country, steam engines are as yet but little known. The time I hope is fast approaching, especially in the coal districts, when our manufacturers will find the advantage of carrying their power to their works, and not their works to their power.

In England nine tenths of all the iron made, is made by the coak of pitcoal: in this country, as on the continent of Europe, the charcoal of wood is used, almost exclusively. I see the day coming when we also shall be driven to the use of pitcoal, of which there is great abundance in many parts of this country. Hence I shall not think it improper in the course of this dissertation to present the reader with facts relating to this kind of fuel; for I am well persuaded that in a few years they will become useful.

Remarks on Iron Ores, the mode of working them, and their general classification.

The following remarks are from Mr. Mushet, 3 Phil. Mag. 193.

IRON-STONES, though commonly denominated ores of clay, contain notwithstanding a variety of mixtures, and may with propriety be divided into the following classes:

1. Iron-stone that has clay for its chief componant earth, and this clay comparatively pure and free from sand.

2. Iron-stone possessing lime for its chief mixture, and this lime also comparatively destitute of sand.

3. Iron-stone that unites clay and lime, containing large proportions of silex; hence, for distinction's sake, these may be denominated siliceous iron-stones. I shall therefore, in naming these varieties, use the following terms as they are arranged in succession. Argillaceous, calcareous, and siliceous iron-stones. None of these earths exist singly with the iron. All iron-stones contain a mixture of the three, in various proportions; from which arise the supposed variety of the qualities of crude iron, which each respective stone is said to contain. There are some, however, which are composed of nearly the same proportions of clay, lime, and silex; and these commonly afford, when compared with themselves, a similar quality of crude iron.

Nature, in the formation of these secondary ores of iron, has invariably impressed characters upon them, easily to be developed: by which means their qualities, and the consequent effects produced in the blast-furnace, may be accurately and distinctly prejudged. The source of this information is, the study of the nature of the united earths; by ascertaining the quantity and proportion of which, we are enabled to pronounce exactly upon the quality of the iron likely to be obtained from the ore. We must not, however, consider these characteristic fea-

tures as a consequence of the metal existing of a variety of qualities; but, *a priori*, we ought to consider, that, as a consequence of the nature and proportions of the mixture, the iron will be called into existence in a state more or less oxygenated or carbonated.

When iron-stones are said to contain *good* or *bad* iron, the expression ought to be understood, which by the bye is seldom the case, only as a comparative assertion, confined to local rules, and judged by certain fixed local standards; into the account of which many things must be taken, which are frequently overlooked. At every iron-work, a certain proportion of fuel, coaks, or wood char, by weight, is understood to be sufficient to smelt, and give principle to a determinate weight and quality of iron-stones combined together, in order that a certain quality of crude iron may be produced. In this case, should a new iron-stone be substituted for one whose quality and effects are already known, and should its application be productive of iron less carbonated than formerly, it would instantly be denominated a *bad* iron-stone, or an iron-stone containing bad iron—an assertion only true comparatively, so far as it would affect the interest of the manufacturer, unless corrected by an addition of fuel, a change of the mixtures of ores, or a varied application of the lime-stone used as a solvent or flux. But this is no proof that the quality of iron, as it exists in the ore, is bad, since a larger proportion of coaks, or a change of mixture, which incurs no additional expence, can correct the evil. It rather furnishes a demonstration that the iron in all ores is the same; but that, in calling it into a metallic form, the quality is affected chiefly by the reduction of those mixtures originally united with it.

As the quality of the fuel is improved in a direct ratio to the quantity of carbon which the coal contains, and its purity, hence arise the great variety of coaks used in smelt-

ing iron-stones; some of which will smelt, and give principle to the iron contained in double the weight of the same ores that others will. From this then may be deduced another proof, that *good* and *bad* iron are terms of comparative meaning only, confined to situation. Let it be conceived that a change of fuel opposite in its quality to that now mentioned was to take place; the same quantity of ore, which with the good coaks would have afforded metal richly carbonated, would now yield its produce in a partial degree, and that highly oxygenated—almost unfit for any purpose. The consequences here entailed are the same, though they may be attributed to different causes; the former as derived from the hostile mixture of the ore, but the latter as arising from a deficiency in the quality of the coaks.

Besides these two leading instruments of alteration in the smelting process, inherent in and derived from the materials, good and bad effects may be produced from an unjust proportion and quality of the lime-stone, which is added, in order that the proper equilibrium may be restored, and the iron properly and beneficially revived.

Taking this then for a general principle, that the crude iron contained in all iron-stones is the same, and that it can be called into existence as a metal of all the various degrees of carbonation, by regulating the proportion of fuel, and of the solvent; I shall proceed to mention those mixtures which I have always observed determine the future quality of the crude iron.

1. Argillaceous iron-stone having fine clay as its chief component earth, lime in the next proportion, and both these nearly destitute of sand; which, when properly torrefied, exhibits fibres on its internal surface, of a brown, dark brown, or claret colour, running either in streaks or radiated, and adhering tenaciously to the tongue, will afford, with a moderate proportion of coaks and lime-stone,

iron of the finest quality, possessing strength conjoined with an intimate degree of fusibility.

2. Calcareous iron-stone, that which contains lime as its principal earthy mixture; holding clay in the next proportion, and both these comparatively unallayed (totally they never are) with sand; which, when regularly torrefied, assumes a variety of shades generally lighter in the colour than the former class; which sometimes, and sometimes not, presents internal fibres, and which adheres less tenaciously to the tongue; always contains iron, which can be revived, richly carbonated with a comparatively small quantity of coaks, and with a trifling addition of lime. Under this class of iron-stones are found those which produce iron of a fusible nature, seldom connected with strength, but valuable for its utility in fine castings, which require ornament more than durability. It is also from this source of mixture that I would trace the red short quality of bar-iron. The nature imposed upon crude iron in the blast-furnace by the developement of its mixtures, most commonly accompanies it through all its subsequent stages of existence as a metal.

3. Those iron-stones whose component parts are nearly an equalised mixture of clay, lime and sand, which torrefy with a slight degree of adhesion to the tongue, assuming a dark-red or brownish colour, void of internal fibre, always afford, with the local proportion of fuel, iron of an intermediate quality for fusibility and softness, but generally possessing strength in an eminent degree. Such iron is excellently adapted for the manufacture of great guns, mortars, and the large species of machinery. Its application to the purpose of bar-iron making, would also be attended with the most beneficial effects, possessing neither the extreme of fusibility nor of infusibility: it would greatly prevent, in the manufacturing, a tendency, which iron possessed of these extremes has, to become red or cold short.

4. Iron-stones which unite a large proportion of sand with sparing proportions of clay and lime, which, upon being slightly exposed to heat, exhibit masses of semivitrification, neither obedient to the magnet, nor adhesive to the tongue, having a refractory disposition to part, and possessing a dark-blue or black colour, always afford, with the usual proportion of fuel, crude iron of the worst quality, either as to strength or fusibility. Such metal is commonly highly oxyginated, and brittle; incapable of being used alone for any melting purpose; and, when applied to the use of the forge, affords malleable iron, which possesses the cold short quality.

These are the four principal classes under which I have arranged our iron-stones, with regard to their tendency to afford their iron carbonated, possessing strength, or otherwise, when smelted in the blast-furnace with a determinate quantity of fuel. As this classification is exactly analogous to the results obtained in the large way, it may serve as a ground-work to those who may wish to attain a practical knowledge of these ores, so far as it relates to their manufacture.

It is however easy to counteract the natural tendency which every iron-stone has in this case, to afford its iron of a certain quality, and to make each of them yield crude iron of all the different degrees of fusibility and strength. Is it not obvious, that since the qualities of crude iron depend upon the mixtures and their kinds composing the stones, that if nature be assisted by adding or subtracting from them in the blast-furnace, every quality of crude iron may be produced from the same iron-stone? I have seen most of these results determined in the large way, and the whole of them beautifully confirmed in the assay-furnace.

It remains with the present manufacturer to consider whether it will be more his interest to reject such iron-stones as are of difficult carbonation, or to apply the neces-

sary additional proportions of fuel, capable of correcting the quality of silicious iron-stones. Not so, however, to those who may at some future period succeed him; necessity, at all times ingenious, assisted by the increasing light which science daily sheds over our manufactures, will devise the means of calling into profitable existence the metal contained in all those ores which may have fallen into disrepute in the present day, or from which at this time it is thought impracticable to extract metal in the large way.

The usual criterions by which iron-stone is judged, whether it be sufficiently rich in iron for the purpose of smelting, are the following:

1. The degree of tenacity with which it adheres to the tongue after torrefaction; 2. Its colour: 3. The obedience to the magnet when pulverised: 4. By depriving of its iron a given weight of the ore, in contact with charcoal and fusible earths in the assay-furnace.

The first and third of these methods are liable to great error. The adhesion to the tongue will be more in proportion to the quantity of its clay and its kind contained in the stone, than to its real contents in iron. Iron-stone may also be torrefied in such a manner as to deprive its internal surface of this property; as it is only peculiar to the stone at a certain stage of torrefaction.

Those iron-stones with which Britain so much abounds, and which are now universally used for the production of cast-iron with pit-coal, are commonly found in horizontal strata, subject to the same acclivity and declivity with the other stratified substances under the surface; their inclination from the horizon varying according to the nature of the ground, and the disposition of the imbedding and incumbent strata. Such variety is exhibited, that strata of iron-stone are found descending 1 yard in 24, 1 in 12, 1 in 8, and sometimes 1 in 4. Where the accli-

vity or declivity of the metals is small, the most extensive and regular fields of iron-stone are to be found, and *vice versa* where the metals lay more on edge.

Iron-stones are generally found imbedded in schistous clay more or less compact, but which moulders away when exposed to air. They assume two different forms: regular connected strata called *bands*, and strata of detached stone found in distinct masses, from the size of the smallest bullet to the weight of several hundred pounds. Those of the small and middling sizes, and which generally wear a flat ovular form, are called *ball-stones:* those of greater weights are by the workmen denominated *lunkers.*

Both these species of iron-stone frequently accompany coal and limestone. In the former case they are commonly incumbent, and found almost in immediate contact with the coal: little extra labour is therefore requisite to bring down the stone; and the double purpose of obtaining both materials is thus advantageously answered.

When iron-stone in bands accompanies limestone, it is most commonly of an inferior quality. Its component parts are chiefly calcareous, and the quantity of iron it contains is small. Ball iron-stones found near to lime are of a much superior quality, and for the most part contain a considerable proportion of iron.

Thus stratified in the vicinity of lime, many iron-stones are found with various impressions of marine remains; and not unfrequently compact and entire shells, univalve and bivalve, are found in the heart of the band. It is however still more difficult to conceive how shells could be deposited, distant from lime, imbedded in iron-stone, incumbent on coal, at the great depth of 80 yards from the surface. In our neighbourhood, at this depth, a small band of iron-stone is found completely covered and interspersed with distinct muscles of an ordinary size.

The Rottenburn iron-stone of Lancashire, consists of a band and an accompanying ball. The former abounds with fine specimens of the ramification of trees, shrubs, &c. In the process of decay, and the substitution of mineral in place of vegetable substance, the more ligneous parts and the bark are distinctly preserved from the heart of the shoot.

This iron-stone contains 37lb. in 100 extremely susceptible of receiving the carbonaceous principle.

Another variety of iron-stone, which we have in this country, and which will be deemed no less curious by the mineralogist, affords maltha, bitumen, mineral pitch, &c. This combustible is found in the heart of large flat rounded balls of iron-stone, occupying a number of interstices, and resembling a cement for the frittered pieces of stone. The distillation of 437 grains afforded me a rough light charcoal, which weighed only 49 grains; this, when exposed to fire in contact with air, burnt without a residue; hence I conclude it to be pure carborn. This iron-stone in the assay-furnace yields 36 pounds of iron in 100.

All these strata of iron-stone bear the most evident marks of the agency of water.

Working of Iron-stone.

When iron-stone is found near the surface, it is only necessary to unbare the soil and the super-incumbent earths: the stone then presents itself like a pavement more or less inclined, and is easily raised by the application of wedges, bars, &c. &c. But as all secondary strata descend, according to the declivity imposed upon them by nature in their formation, it is obvious that, in proportion as the excavation extends at right angles to the line of level, the stone becomes gradually buried under an accumulating depth of earth, till such time as the expence of throwing this off exceeds either the value of the stone, or

the expence at which it could be procured by a different mode of operation. It therefore becomes necessary to make perforations by means of horizontal galleries, extended under the soil, so as to fall in with the declivity of the strata: these catch the inclining stone for a stretch of 100 to 240 yards, according to the existent circumstances of the mine.

These galleries are in Scotland called the barrow roads. Whenever the miner has arrived at the extremity of his working, he turns round and commences an excavation on his right and left hand, proportioned to the rise and dip of the stone, to the extent of several yards on each; the accompanying shist and rubbish are packed into the vacuity behind him: should there remain any superfluity unpacked, it is wheeled to the mouth of the gallery along with the iron-stone. In this manner the miner returns, and brings along with him the whole iron-stone contained in 100 to 240 yards in length, and in 20 to 30 yards in width. The height of the gallery is commonly so small, that the miner is obliged to perform his work upon his side: the wheelers are likewise obliged to push the barrow on all fours. This species of working is called under cover; and the attainment of a band of good iron-stone, though only four inches thick, will sufficiently defray the expence of the operation. It is here also obvious, that this operation can only be carried a certain length in the same gallery, till such time as the expence of wheeling out the stone must exceed the value of that share of labour generally appropriated to it. A more economical method is therefore indispensibly requisite. This is effected by sinking a pit 160 to 200 yards farther on the same line of level. When the iron-stone is found, the miner sets off another gallery, or barrow road, towards his former working, and continues till he meets the termination of his *old waste:* as formerly, he now begins his retreat, and carries

with him a similar portion of iron-stone from each side of the gallery. The quantity of iron-stone by weight obtained from such a *working*, depends entirely upon its extent and the thickness of the band. A square yard of iron-stone containing 9 cubical feet, as it lays stratified, will weigh from 1850 to 1900 pounds weight. The other side of the pit is next perforated, and the same operation completed. When the iron-stone is thus exhausted, another pit, sunk at a similar distance from the termination of the second gallery in the first, opens up a new field of supply. In this manner iron-stone is continued to be raised, till such time as the *field* is totally exhausted.

These extensive excavations commonly collect a considerable quantity of water, which would soon impede the progress of the workmen: various means have been contrived to remove this consequent obstruction. These have chiefly consisted in running a counter gallery as far to the declivity of the *metals* as possible, and of passing the water into it by means of filtration, or communications betwixt gallery and gallery. Where a sufficient quantity of running water presents itself, water-wheels have been applied, to extract the water from one general reservoir by means of pumps.

Strata of iron-stone are from 1-2 an inch to 12 inches in thickness. Those of 3, 4, 5 and 6 inches are most commonly met with; they are also reckoned to contain a quantity and quality of iron superior to larger bands. Ball and lunker iron-stone, however large, contain always a superior quantity of iron, and are easier reduced in the blast-furnace. *(Mushet.)*

On Iron Ores particularly,

1st. As to the state of the iron as it is contained in the ore.

2dly. As to the quantity of the iron contained in the ore.

3dly. As to the kinds and proportions of earths, with which the iron ore is mixed.

As to the *state* of the iron as it is contained in the ore.

Iron ores contain the iron either combined with sulphur: or with sulphur and arsenic; or mixed with copper ore: or with manganese: or in the state of an ochre or oxyde: or in the state of what the chemists call an oxydule, frequently magnetic and more approaching to the metallic state: or combined with acids, and forming saline substances, such as green vitriol, &c.

The sulphuretted ores, are usually called Pyrites; they are often of a metallic gold colour, hard, and brittle, giving fire with steel. These are seldom worked, unless to collect the sulphur, or to make green vitriol. But several ores worth working, contain also sulphur, or arsenic, or both. This can be ascertained by reducing them to powder, and exposing them to a cherry-red heat, when the smell will generally detect both the sulphur and the arsenic. The fumes of the latter also, will whiten copper.

Ores much mixed with copper, can seldom be worked with profit in a furnace. The mixed metal is brittle and bad. Some ores at Cornwall furnace, (Mr. Coleman's) are of this kind, and are not worked.

Ores are very often mixed with a notable proportion of manganese, as I have seen them at the Dunham works, that formerly belonged to Jos. Galloway. This mixture is a detriment, though of late it has been proposed to give the properties of steel to iron by means of manganese, in a large way. These ores are blackish, and give a full green slag with common white glass and potash as a flux. Nickel, Crome, and Phosphorus are also frequently combined with iron, but it requires much chemical skill to separate them accurately. In a large way, they must be separated in the bloomery and by the hammer.

The oxydes of iron, and the iron combined with carbo-

nic acid, are usually worked to profit, as in the common mountain iron-stone, and the bog-ores.

The salts of iron (unless the carbonat of iron be so called) are never smelted for the purpose of obtaining metal.

Whether an ore be magnetic or not, is no criterion whether it be worth working or not. This quality has influence only on the quantity of carbonaceous matter necessary to metallize the iron.

As to the *quantity* of iron contained in an ore. Whether it be worth working or no, depends less upon this criterion, than upon the circumstances, whether it can be easily gotten, and easily and cheaply fixed. The shining sulphureous pyrites often contains more than fifty per cent of metal, and is not worth working: the poor ore of Staffordshire, in England, that does not yield more than from 16 to 20 per cent, is a profitable concern, because it is easily reduced to a metalline state, and when so reduced is of good quality.

As to the kinds and proportions of *earths* with which the stone is mixed. Let it be remembered, that,

The earth that gives the character to common clay, and to clay stones is called *argillaceous* earth. The earth that gives the character to limestone, is called *calcareous* earth. The earth that gives the character, to quartz, flint, whether transparent or opaque, to flinty sandstone and stones of that hard nature, which scratch glass, and give fire with steel, is called *siliceous* earth. The earth that gives the character to soapstone, and stones of that class, that appear soft and greasy to the touch, is called *magnesian* earth. Iron-stones contain the latter in so small proportion for the most part, that its effects need not be noticed: but the rest are of great importance to be known; for whether any limestone ought to be added as a flux, or in what proportion, depends on the kind and quantity of the earth, that envelopes the particles of iron.

Before I class iron ores in this respect, I would observe, that it is necessary to bring the iron into a metalline state which is done by charcoal and heat. Also, that when brought into a metalline state, it will not fall down and unite in one mass, but be enveloped in separate particles among the coals, unless the coals and the earths of the stone, are brought into fusion, and made into a glass so thin that the particles of metal by their superior weight, will fall through them. This is done by knowing in what way the earths can be so mixed, as to be brought into thin fusion, by the usual fire of a furnace.

On the fluxes of Iron ores.

The principles on which all earthy fluxes depend, is, that no earth is fusible alone—that argillaceous and siliceous earths together are infusible—that argillaceous and magnesian earths together are infusible—that silicious earths and magnesian earths together are infusible—but that when lime or limestone (calcareous earth) is added to any mixture of the other two, they will run into a glass, which will be thin and fluid with the same application of heat, in proportion to the judicious mixture of the several earths. M. D'Arcet, a French chemist, made this experiment: He put into one crucible a round marble of clay, into another a ball of the same size of quartzose or silicious sandstone, into another, a ball of the same size of chalk; and exposed them to a violent heat in the same furnace for the same length of time. They were all uncharged, except where the chalk ball had touched the crucible; in that place, there was the appearance of fusion. He put all three balls together, first reducing them to powder and mixing them. In a short time the same furnace melted them into a transparent glass.

Moreover the experiments of Mr. Kirwan have ascertained

That argillaceous and siliceous earths—argillaceous and magnesian earths—siliceous and magnesian earths, would not melt in whatever proportions they were mixed. That siliceous and calcareous earths—argillaceous and calcareous earths, by very strong heat might be vitrified, but not into a perfect and thin glass.

That when the earths are calcareous, argillaceous and magnesian, it requires that the lime should be in a double portion to make a glass.

That no glass can be produced if the clay-earth or the magnesian earth predominate.

That calcareous earth, argillaceous earth, and siliceous earth—or, calcareous earth, magnesian earth, and siliceous earth—can be brought into perfect fusion if the calcareous earth somewhat predominate. And that by means of a strong heat, a perfect glass may be produced by siliceous, argillaceous and magnesian earths alone, without lime: and that this is the only combination he tried, in which limestone earth was not absolutely necessary in the mixture, to make glass.

He further ascertained, that all the metallic oxyds, and of course that of iron, assisted in producing fusion: also, that common clay contains one half or more of its weight usually of sand, intimately mixed.

Hence limestone earth, or calcareous earth, may be regarded as the substance most fit in an economical point of view to bring other earths into thin fusion; for which purpose it should be in the proportion of 1 1-2 or nearly 2 to 1 of that earth which predominates in the iron-stone.

Hence, if clay predominate in the iron-stone, (or earth of which pure clay is the basis) the flux is limestone: and on the contrary if the iron be mixed with limestone, the proper flux is not limestone, but clay.

Also, that herein consists much of the practical knowledge of assorting ores, namely to mix together such ores,

Before I class iron ores in this respect, I would observe, that it is necessary to bring the iron into a metalline state which is done by charcoal and heat. Also, that when brought into a metalline state, it will not fall down and unite in one mass, but be enveloped in separate particles among the coals, unless the coals and the earths of the stone, are brought into fusion, and made into a glass so thin that the particles of metal by their superior weight, will fall through them. This is done by knowing in what way the earths can be so mixed, as to be brought into thin fusion, by the usual fire of a furnace.

On the fluxes of Iron ores.

The principles on which all earthy fluxes depend, is, that no earth is fusible alone—that argillaceous and siliceous earths together are infusible—that argillaceous and magnesian earths together are infusible—that silicious earths and magnesian earths together are infusible—but that when lime or limestone (calcareous earth) is added to any mixture of the other two, they will run into a glass, which will be thin and fluid with the same application of heat, in proportion to the judicious mixture of the several earths. M. D'Arcet, a French chemist, made this experiment: He put into one crucible a round marble of clay, into another a ball of the same size of quartzose or silicious sandstone, into another, a ball of the same size of chalk; and exposed them to a violent heat in the same furnace for the same length of time. They were all uncharged, except where the chalk ball had touched the crucible; in that place, there was the appearance of fusion. He put all three balls together, first reducing them to powder and mixing them. In a short time the same furnace melted them into a transparent glass.

Moreover the experiments of Mr. Kirwan have ascertained

That argillaceous and siliceous earths—argillaceous and magnesian earths—siliceous and magnesian earths, would not melt in whatever proportions they were mixed. That siliceous and calcareous earths—argillaceous and calcareous earths, by very strong heat might be vitrified, but not into a perfect and thin glass.

That when the earths are calcareous, argillaceous and magnesian, it requires that the lime should be in a double portion to make a glass.

That no glass can be produced if the clay-earth or the magnesian earth predominate.

That calcareous earth, argillaceous earth, and siliceous earth—or, calcareous earth, magnesian earth, and siliceous earth—can be brought into perfect fusion if the calcareous earth somewhat predominate. And that by means of a strong heat, a perfect glass may be produced by siliceous, argillaceous and magnesian earths alone, without lime: and that this is the only combination he tried, in which limestone earth was not absolutely necessary in the mixture, to make glass.

He further ascertained, that all the metallic oxyds, and of course that of iron, assisted in producing fusion: also, that common clay contains one half or more of its weight usually of sand, intimately mixed.

Hence limestone earth, or calcareous earth, may be regarded as the substance most fit in an economical point of view to bring other earths into thin fusion; for which purpose it should be in the proportion of 1 1-2 or nearly 2 to 1 of that earth which predominates in the iron-stone.

Hence, if clay predominate in the iron-stone, (or earth of which pure clay is the basis) the flux is limestone: and on the contrary if the iron be mixed with limestone, the proper flux is not limestone, but clay.

Also, that herein consists much of the practical knowledge of assorting ores, namely to mix together such ores,

as may contribute to flux each other, being with difficulty fluxed alone.

Hence also, appears the necessity of this knowledge, in order to save coals, to save time, and to prevent the iron from being entangled and enveloped in a thick unyielding refractory slag, or scoria.

Hence also, the necessity of beginning your operations, by trying what earth, and in what proportions your ore contains: that is, to analyse your ore.

Of course, my next section will treat of

The Analysis of Iron ores. Chemists usually agree that the constituent parts of an ore, cannot be accurately known unless by analysing it in the moist way; that is, by solution in acids or alkalies, and by precipitating the substances dissolved, by means of what are called reagents. I am of this opinion too. But such an accurate analysis is not practically necessary, nor is it practically true: for in the course of operations of a large manufacture, it is not to be expected that the iron yielded by a thousand ton of ore, will correspond with the result of the analysis of an ounce.

The best mode in my opinion is to proceed in the small way, pretty nearly upon the same plan that you proceed in the large way.

The two objects then are, first, to find out what proportion of flux your ore will require, and of what kind, so as to be fused most compleatly at the slightest expence. 2dly. Find out how much iron you can procure by means of fire and fluxes, out of a given weight of ore.

If you have not the means of a good wind furnace, you must go to a blacksmith's shop for the purpose. But every establishment of iron works, ought to have an assay furnace, of which the surface, should be 3 feet from the ground: the furnace hole 20 inches deep, 14 inches wide at the bottom, 12 inches wide at the top: the cruci-

ble-stand, should be 6 inches high from the centre of the grate, wherein there should be an even platform of 4 inches diameter to receive it and enable it to stand steady. At 6 inches from the top of the furnace there should be an horizontal side flue of 6 inches by 6 inches, and 9 inches long, with one end opening into the furnace, and the other into the upright chimney. The chimney should be 6 inches by 9 inches or thereabout, and not less than 20 feet high. The cover should be of fire clay mixed with burnt brick, well beaten, and burnt, and enclosed in a wrought iron frame with a handle to lift it on and off by. This cover should fit accurately to the surface of the furnace, and be at least 14 inches square. With such a furnace, heat enough may be given for most experiments, especially if about 1-2 of the coak of pitcoal be mixed with the charcoal; neither of these ought to be used in lumps bigger than a small egg. The inside of the furnace ought to be lined with refractory or infusible fire clay over fire brick; or else with a mortar of pounded clay mixed with pounded soap stone. Mushet's assay furnace with a pyrometor measuring the degrees of heat, is to be found in 4 Philos. Mag. 255. but I like my own as well. The powerful three-blast assay furnace of the French school of mines, is delineated in 14 Philos. Mag. 69. It is worked by 3 equidistant tweers. It should be remembered that both in England and France, the men of science in their laboratory, and the men of experience in the iron manufacture, have gradually encreased the admission of air into their furnaces, and divided the quantity between two tweers.

The first process I would advise should be to ascertain whether there be any limestone in your ore, and how much. For which purpose

Take 400 grains of the ore in fine powder, from among the powder of at least half a dozen fair specimens of the mine:

Pour on it in a glass tumbler half an ounce by measure (by means of the common graduated measuring glasses used by apothecaries and chemists) of common spirit of salt, to which add twice as much water. Expose it to a heat nearly boiling for half an hour. If there be no effervescence, there is probably no limestone. If there be, continue to add by small degrees, spirit of salt and water, till all effervescence is fairly over. Let it stand 3 or 4 hours. Then add half a pint of water, stir it well, and filter the whole through (unsized) filtering paper. Wash what remains on the filter, with half a pint more of water, and add the filtered liquors together. This will dissolve all the limestone earth, and perhaps some of the ore, and a small portion of the argillaceous earth, but these last are of no consequence.

Then add to the filtered solutions, two drams by measure of oil of vitriol, which will throw down the limestone earth in a thick sediment in the form of gypsum or sulphat of lime. Let it rest, and add a few drops more of the oil of vitriol, until no fresh sediment any longer appears. Pour off the supernatant clear liquor: add half a pint of hot water, and filter: wash the filter with two more half pints of hot water, until the liquor that passes through, is no longer sensibly acid. Let the filter remain to drain for 24 hours. Scrape off all the sediment, put it in a cup or a saucer to dry for at least six hours on a common iron stove, or 120° of Fahr. let it so remain till dry and powdery to the touch; when 150 grains will designate 100 grains of limestone. Or else (which is more accurate) expose it for half an hour in a crucible to a red heat, when 135 grains will designate 100 grains of limestone.

The limestone may be generally, ascertained also, by means of the air it contains, but it requires some little knowledge of pneumatic chemistry. Thus, weigh a common pint decanter, that will hold a full pint. Balance it in the scales. Put into it, 1lb. avordupois weight of water,

at the temperature of 60 of Fahrenheit's thermometer. Now as 44 grains of chalk will yield air, equal to that bulk of water, one pint of air will designate 44 grains of pure limestone. This can be done by fixing a tube of tin, or copper, or glass, bent like the letter S into a cork. Insert the cork in the bottle or vial which contains your mixture of spirit of salt and water with the ore to be tried. Invert the pint decanter full of water in water, and let the air displace the water of the inverted decanter.

Having thus ascertained the quantity of limestone if any, you will have a guide how much to add, when you know the proportion already contained in the ore. If the ore be, as it often is, an argillaceous ore, which can be told by putting your tongue to it, which will adhere; or by the earthy smell perceived on breathing on it, it will require more limestone in proportion to the clay. Calcareous ores and siliceous ores, do not emit an earthy smell or adhere sensibly to the tongue.

If your ore be a calcareous ore, that is, inveloped in limestone, it would be absurd to use a limestone flux; your flux should be half its weight of clay. If it be a siliceous ore it will require both limestone and clay. Nor is it the *quantity* of iron alone, that depends upon the due mixture of the earths which are to form the flux: the *quality* and appearance of the iron produced, equally depend upon the same circumstance: and it may be safely taken for granted, that when an ore is well deprived by roasting of its sulphur or its arsenic, if there be any, and when the due proportions of coal for heating and metallizing, and of earths as a flux are known by well ascertaining the component parts of the ore, every ore may be made to furnish the same kind of iron.

Directions for assaying ores in the small way, by the same process that is employed in the large way, are given in the following papers of a practical and experienced iron

master, which are better than any thing of the kind I have seen elsewhere, though intermixed with some speculation.

On the Assaying of Iron Ores and Iron Stones by Fusion. By Mr. DAVID MUSHET, *of the Clyde Iron Works.* 4 *Phil. Mag.* 178.

In our manufactories, the just combination of art with science is what we can seldom boast; in authors, the same happy union of theory and practice is also markedly deficient; and we have constantly to regret, that the want of liberality in the individuals of the one class, and opportunity in that of the other, prevent us from feeling the happy effects of this so much desired union.

The process of depriving ores of their metal by fusion in the assay-furnace, and that part particularly relating to iron, which I mean to make the principal subject of this paper, lead me more immediately to make these observations. With the manufacturer, in general, the uses and propriety of the assay-furnace are seldom admitted, or, at best are restricted to such narrow limits as to be only capable of ascertaining the quantity of iron contained in ore or iron-stone. The chemist, on the other hand intent only upon effecting his operation, and of giving accuracy to the result, confines his observations to a certain chain of science, and seldom or never considers manufactures as the ultimate and happy end towards which his labours should be directed.

With whatever deference and respect we look up to the names of men celebrated for their indefatigable zeal and industry in the cause of science, and with whatever satisfaction we rest upon the result of their labours as to truth; yet, in general, the practical man feels dissatisfied with the manner in which those subjects are treated which come more immediately under his own observation.

It is I fear with some truth that this charge is brought against that part of the arts relative to the assaying of iron ores. We never find, in the works of those whose attention has been directed to this subject, that the least connected idea ever exists betwixt the assay and the blast-furnace, or that the agents used for reduction in the laboratory, can in general be applied to works in the large way. A total silence prevails amongst authors of this class, as to the various qualities of crude iron which certain ores and certain combinations of fluxes produce: all ores, however various, are reduced to the same complex treatment, and the operation itself measured by minutes, as if the fusibility of all the widely differently-combined ores was the same.

The celebrated Bergman even, has a degree of complexity in his receipts for the assaying of iron ores, that seems unworthy of the simple elements of science. The following one in particular seems to possess an air of incongruity even in the proportions, only equalled by the oddity of the assemblage of mixtures brought forward:

"100 Grains of the roasted ore, two parts of the black "flux, (equal parts of borax and nitre,) one part of tartar, "one of sal-ammoniac, one of sandever, half of (again) "borax, half of glass, one-fourth of *clean soot*, one-fourth "of charcoal; the whole to be covered with common salt." This motly association of earths, alkalies, and salts, is recommended as the best flux for ALL iron ores. The author however shews, that the advantages which it possesses are not complete, from the great caution prescribed in the mode of conveying the necessary degree of heat; and the perfection of the operation is rendered altogether doubtful by the consequences which the oversight of a *few minutes* may occasion.

It cannot be well reconciled to our ideas of advancement in any art, that we have not yet discovered a method

of operation more perfect than that, wherein a few minutes lost or gained (which error will more likely take place from the inequality of heat, than the reckoning of time,) make a variation from truth equal to 1-5th or 1-6th of the whole. The manufacturer would be in a lamentable predicament were he thus circumstanced, and obliged, by some means or other, to take the crude iron from the blast-furnace immediately upon being separated from the ores, lest a considerable portion of it should totally disappear. If the degree of heat produced from a smith's forge was at all times the same, though supplied with fuel of various natures, and under different changes of temperature, then it is most probable that, by reckoning Bergman's time to a minute, a button of iron, accurate in its results, might be obtained from *some* ores by the flux he has directed to be used. But I cannot conceive that this should be an universal consequence: far less can I comprehend, after a just separation has been effected, that five minutes will destroy 1-10th of the produce of metal, while the incumbent fluid protects the surface of the metallic button from the action of the atmosphere.

It is not, however, my province to enter into a minute examination of the products obtained from the use of such vitreous fluxes, which are always productive of the most oxygenated state of crude iron; and the accuracy of whose results, under a state of such high oxygenation, are always to be suspected. I have frequently proved that, in using them, the affinity of the metal was so great to oxygen, that a slight derangement of the crucible, which had thrown the vitrified fluid from any point of the surface, was immediately attended by a rapid deflagration, and a considerable portion of the iron oxydated.

I shall chiefly confine myself to a communication of those facts, which I have repeatedly confirmed, with a view of extending my results and observations to a more

extensive scale. I have constantly considered the assay-furnace as capable of affording conclusions applicable to the operations of the smelting-furnace, and that change or innovation should always have the concurring testimony of truth to back them, though, on a small scale, before they be risqued on one more momentous or extensive. Influenced by such motives, I early rejected, as totally inapplicable to the scale of manufacture, the numerous tribe of salts, alkalies, and earths: these, in the application, are subject to no rule, nor guided by any immediate object of general utility, but are as arbitrary as their authors are numerous. On the contrary, I have directed my endeavours to the use of such agents as effect separation upon the large scale, and have been fortunate to find that the same solvents, when properly applied, are productive of the most perfect and finished results. By the simple application of lime or chalk, in various proportions, as a calcareous earth, and common bottle glass, in the place of silex, to constitute fusibility, I have been able to produce in the assay-furnace, all the various qualities of crude iron, as to strength and fusibility. In no case has the result of any assay been considered perfect, unless the vitrid mass found upon the surface of the metallic button exhibited a degree of transparency and purity of colour little inferior to flint glass, or slightly darkened by a faint shade of azure. In such vitrifications, purity of colour is the surest proof of the non-existence of iron in the state of a fused oxyde: the same degree of pellucidity renders it easy to detect the smallest globule of metal which by chance may have been suspended during fusion. In all experiments where a just association of mixtures has been present to produce this peculiar scoria, the quality of the iron will be found richly carbonated, and the button possessing a smooth, silvery, greasy-feel surface. On the other hand, experience has repeatedly shewn, that when the scoria ob-

tained in assaying approached not to the colour and purity of fine glass, there remained a portion of the iron still unrevived, in the state of a fused ozyde, conveying colour and opacity to the mass; that at certain degrees of colour, certain degrees of opacity existed, and proportionate quantities of the metal remained diffused in the scoria. When the colour of this was green, the quantity of metal united was small; but as the green deepened, and became associated with light browns, the quantity of unrevived iron was greater, and became much increased as the scoria assumed darker browns, or became totally black: in such instances I have found it contain, upon being reassayed, 12 *per cent.* The assaying of iron ores is susceptible of another extreme, by which experiment is equally clogged, and wherein it is very difficult to obtain an accurate result. In this case no perfect button of metal is found, but the portion of iron which the ore contained is in a vast variety of various sized globules of the richest crude iron, interspersed in, or covering the surface of a semi-vitrified opaque mass of scoria, of a greyish-blue, mottled, or whitish colour. The causes of which, and their strict analogy to similar results in the blast-furnace, shall be my chief object to explain.

In a former paper I mentioned, that if iron-stones were smelted without the addition of any other substance, the product in iron would be proportioned to the quantity of lime contained in the respective classes. We shall see from the following experiments how far this is confirmed by means of the assay-furnace, and furnish to ourselves one important lesson, how far the various mixtures of ores affect the operation of smelting?

1st, Into a crucible, with a well-fitted cover, I introduced 875 grains of a pulverised *siliceous* iron-stone in its raw state, and applied such degree of heat as is usually given in such operations. In twelve minutes I found

that the iron-stone was in perfect fusion, much agitated, and emitting large bubbles of ignited gas of a fiery colour. In forty minutes the crucible was withdrawn; the surface of the vitrified fluid still continued to boil, and emit bubbles of air, though in much less quantity. In this state I introduced a small rod through the scoria, and discoverd the surface of a button of metal. The moment it came into contact with atmospheric air, a beautiful combustion took place; the metal rose in a spiral form to supply the rapid inflammation, and continued till the scoria (still in fusion) closed over the surface of the button. When cold, I found a perfect formed button of extremely oxygenated crude iron, which weighed 219 grains; a produce equal to 25·1 *per cent.* from the raw iron-stone. The scoria obtained was of a shining black colour, firm and ponderous, and weighed 402 grains; so that the loss in volatile matter was 254 grains, equal to 29 *per cent.*

Although this iron-stone was siliceous, yet I am convinced the loss of volatile matter would have been greater, had not nearly one-half of the whole contents of iron remained in the scoria, united with oxygen, at the rate of 35 *per cent.* I found the produce of the metallic button thus obtained white as silver, and presenting imperfect radii; the surface was considerably oxydated, especially where the combustion had taken effect.

2d, I subjected to a similar treatment 875 grains of an *argillaceous* iron-stone, which contained a usual proportion of lime; the fusion of this powder was more difficult than that of the former, though the phenomena exhibited by both during reduction were alike. The crucible was withdrawn from the furnace in forty minutes after introduction, and the surface of the button exposed to combustion as before. The deflagration differed little in point of appearance from that effected with the siliceous iron-stone: the button of crude iron was found oxygenated,

and weighed 249 grains; a produce in iron from the raw stone = 28.5 *per cent.*: the vitrid mass was found to weigh 354 grains; the loss of volatile mixtures was therefore 272 grains, or 31 *per cent.* The fracture of the regulus now obtained was still white, though not allied to any degree of crystallisation, and its surface smoother and less oxydated. The glass produced in this experiment was of a deep brown shining colour, in many places porous, and enriched with fine tints of colouring.

3d, The same experiment was repeated upon 875 grains of a fine *calcareous** iron-stone. The fusion of this required a violent heat of seventeen minutes, during which time the disengagement of a gaseous substance was most evident; in other respects it exhibited the same features, when in fusion, as the two former: the degree and length of heat conveyed was nearly the same; and the result obtained was a button of carby-oxygenated crude iron weighing 261 grains; a produce in iron equal to 30 *per cent.* from the raw iron-stone; fused earths, now reduced

* I omitted to mention (p. 37) another method of ascertaining the quantity of calcareous or limestone earth in an ore. Pure limestone contains 44 parts in 100 by weight of air (carbonic acid gas). Take a Florence flask, or the round bottom of a Florence flask, put it on one side of a pair of scales; pour into it one dram by measure or 100 grains by weight of spirit of salt, and as much water. Put weight in the other scale to balance this. Then pour into the acid liquor your ore in powder, and let it remain for an hour. Whatever limestone it contains will be dissolved, and the quantity can be told from the weight lost: suppose the loss 10 grs.: then as 44 is to 100, so is 10 to the limestone contained in the ore. This will be accurate wherever the iron in the ore is not in a metallic state; if it be, air will be given by the iron, which a chemist can separate by means of lime water. But few ores will be liable to this uncertainty.

Oxyd, Oxydation, metal combined with xoygen or pure air, which must be separated from it by means of carbon or charcoal.

Carbonated, carbonation, the uniting pure charcoal to an ore, which converts it into a metal. T. C.

to an opaque brown glass streaked with white, 294 grains: loss in volatile mixtures 320 grains, or 36.5 *per cent.*

The metallic button produced in this operation had a smooth crystallised surface; and, when in fusion, combined less readily with oxygen offered by the contact of atmospheric air, than did the former two. The fracture was light grey, with a regular distinct grain; the mass of fused earths were disposed after the manner of a crystallisation, in radii, shooting from the circumference of a minute circle to the extremity of one larger.

From these experiments it is obvious that reguli of crude iron may be obtained from the different classes of iron-stones, of a respectable produce, without any addition whatever; and that the tendency which these have to part with their iron is in the exact ratio of the quantity of lime present. The following statement exhibits the difference betwixt the real and partial assay of the foregoing iron-stones.

The siliceous iron-stone properly assayed, yielded 34.5 *per cent.* but by fusion *per se** only 25; leaving in the latter method 9.5 mixed with the scoria. Argillaceous stone, properly assayed, gave 35.6, by fusion *per se* 28.5; leaving 7.1 mixed with the scoria. Calcareous iron-stone, properly assayed, yielded 33.7, by fusion *per se* 30; which left 3.7 mixed with the scoria.

One reason may be advanced why the iron produced from the calcareous stone was so much more in proportion than the other two classes: both the siliceous and argillaceous buttons, when deprived of their scoria, decomposed atmospheric air so rapidly as to suffer a little, in point of real metal, from the combination of oxygen. It was otherwise, however, when the surface of the calcareous button was exposed: the affinity of the oxygen to the metal being less than to the carbon united with it, carbonic acid was formed. A review of these experiments leads to

* By itself: without addition.

another conclusion, that without the presence of carbon, either in chemical union in the ore, or attracted from the ignited gas by the particles of metal, crude iron will not separate from the ore or stone; and that, in proportion as the metal is exposed to inhale this principle, its produce is increased and its quality improved.

It will further appear obvious, from the various natures of scoriæ which the different iron-stones afford when fused *per se*, that there exists a want of mixture in most of them to form, when fused, a fluid so sufficiently divided that no portion of iron may be retained, either in a metallic state, or in that of an oxyde. This deficiency of mixture is greatest in the siliceous iron-stones, less in the argillaceous, and least of all in the calcareous. The principle, therefore, I proceeded upon was, to ascertain what proportion of additional mixture, and of what nature, was necessary to give the proper equilibrium to form a transparent slag or scoria. When silex predominated, it was found that a major proportion of calcareous earth, in the solvent or flux, supplied the natural deficiency; and that the whole contents in iron were justly revived, and fully saturated with carbon: when at any time it was wished to revive the metal, contained in such ores, possessing strength with carbonation, I found that this could be easily effected, in all proportions, by the addition of calcareous earth with a mixture of pure clay. In short, in every experiment I have made with ores, the various natures of lime-stones, or chalk, with certain proportions of bottle glass, have been found capable of reviving the iron contained in all the ores which have come under my knowledge, and of conferring upon their respective products every degree of strength and fusibility *. In order to form an accurate

* Although I have frequently had occasion to mention the combination of clay with iron-stone, as the mixture which in fusion conveyed strength to the metal, yet I have not ventured a conjecture

judgment of the tendency which individual ores have to afford their metal carbonated, possessing strength, or otherwise, a flux of a medium proportion of calcareous earth and glass is determined upon; such as, with an iron-stone of that genus, would afford super-carbonated crude iron. Let the button of iron so obtained be the standard whereby to judge of succeeding results; and let all the ores belonging to the same mine, or used at the same work, be compared with it: these will be found, according to their mixtures, possessing different degrees of carbonation; some of them white in the fracture, and others again as richly carbonated as the standard regulus; their degrees of strength also approaching or receding from the standard as they approximate or vary from the nature and proportion of its original mixture.

To complete such an undertaking with accuracy, requires a minute knowledge of the operations of the assay-furnace, and the degree of heat from time to time excited: the quantity of ore in such a chain of experiments should

how far and in what manner the mechanical structure of the metal is altered when additional strength is thus obtained. It will be a difficult matter to decide, whether it is derived from the natural infusibility of the clay, by preventing separation for a longer time, and new modifying the structure of the particles of metal; or whether the acquired strength is entirely owing to the moleculæ of the metal becoming more flattened and tenacious by a varied stage of crystallisation. Most probably it is owing to both causes, and that the former is productive of the latter; the one the cause, and the other the effect accounted for.

We find, that from siliceous iron-stone, which is fused with the greatest facility, iron is obtained uncommonly white and brittle; and again, from pure calcareous iron-stones, which are still more difficult to reduce than the other two classes, we find an opposite extreme of brittleness, arising from an extra combination of carbon, which destroys the continuity of the particles to each other. Clay still holds the medium; and its addition alone restores a just equilibrium, not of strength only, but of fusibility. Mushet.

be at all times the same, and the requisite heat conveyed and completed at similar stages of fusion and of separation. Strict accuracy of result, as to the quantity of metal, will not always be obtained; but a very comprehensive knowledge will be formed of the nature of the earthy mixtures, and the strength and fusibility of the metal. Once in the possession of these, it will be no difficult matter to superadd a portion of earths requisite for perfect reduction. In two simple experiments, therefore, not only the real quantity of metal contained in the ore is obtained, but its presumptive strength and fusibility developed in a great measure prior to its application to the purposes of the blast-furnace."* * * *

'It will easily be conceived, from the mode of operation which I have adopted, that, in order to procure accurate results, the proportion of flux must be varied according to the mixtures in the iron-stones or ores; and that no universal solvent can be used as capable of assaying *all* ores.

As the gradation of mixtures in the ores is almost imperceptible, there are, in fact, no fixed limits by which Nature has distinguished the various classes: we find all the varieties diminishing their predominant earth, and assuming, in equal proportions, those of each other, thus constituting the class of equalised mixtures; yet, here, the variety of combination ceases not, the predominating earth gradually becomes the minor part of the mixture, and that which only held a second rank, as to quantity, is now the chief component earth; the permutation goes round, till the earth, which existed in the most sparing quantity, now predominates to excess.

In such an infinity of variation, it is difficult to arrange the combinations of which these substances are capable. To derive the name of a class, or genus, from the predominancy of an earth, seems most eligible; and to consider

those as varieties of the same class, which are altered by the proportion of the second and third mixtures. Again, each of these varieties are susceptible of a multiplicity of modifications before an earth is so far diminished as to give an ascendency to another, or before the third rank of proportion has assumed that of the second or first. The simple combination of the earths, and their degrees of predominancy, may be thus arranged:—

	1st Variety,	2d Variety.	
Argillaceous iron-stone	Iron - -	Iron	As these become varied, they form the class of equalised mixture.
	Clay - -	Clay	
	Lime - -	Silex	
	Silex - -	Lime	
Calcareous iron-stone	Iron - -	Iron	
	Lime - -	Lime	
	Clay - -	Silex	
	Silex - -	Clay	
Siliceous iron-stone	Iron - -	Iron	
	Silex - -	Silex	
	Lime - -	Clay	
	Clay - -	Lime	

To assay any of these varieties, a flux peculiar to the nature of the mixture is necessary; so that the changes of proportion in the solvent ought to extend to seven, including the class of equalised mixtures, in order that the precise same quality of crude iron may be produced from all the varieties of iron-stone. The modification of each variety will be found to be sufficiently accurate, if assayed by the flux peculiar to itself. The arrangement of the three classes of ores into two varieties, each forming a distinct stage of combination, indicated by the predominancy of the first and second earth, are, with the neutral class, sufficiently minute for any purpose in the assay-furnace, and are sufficient to form an accurate and extensive knowledge of the analogy of these results with those in the blast-furnace.

Table of Proportions of Fluxes.

Let the earthy part of an argillaceous ore be composed of clay 9, lime 6, sand 3 = 18.

To assay	4	troy ounces of this ore --	or	1920 grains,
add	4	——— bottle glass	—	1920
	3	——— chalk	—	1440
	$0\frac{1}{2}$	——— charcoal	—	240
	$11\frac{1}{2}$			5520

Let the second variety of argillaceous ores contain, clay 10, silex 7, lime 3 = 20.

In this case,	4	ounces troy of ore --	or	1920 grains,
would require	4	——— bottle glass	—	1920
	4	——— chalk	—	1920
	$0\frac{1}{4}$	——— charcoal	—	360
	$12\frac{1}{4}$			6120

Let the first variety of the calcareous genus of iron-stone be supposed to contain, of earthy mixtures, lime 14, clay 6, silex 4 = 24.

When this iron-stone is to be assayed,

to	4	ounces troy - -	or	1920 grains,
add	5	——— bottle glass -	—	2400
	$1\frac{1}{2}$	——— chalk - -	—	720
	$0\frac{1}{4}$	——— charcoal -	—	360
	$11\frac{1}{4}$			5400

Again, let the second variety of the calcareous genus be supposed to contain, lime 10, sand 6, clay 4 = 20.

I would add to	4	troy ounces -	or	1920 grains,
	4	——— bottle glass	—	1920
	2	——— chalk	—	960
	$0\frac{1}{2}$	——— charcoal	—	240
	$10\frac{1}{2}$			5040

Let the first variety of siliceous ores be supposed to contain, silex 12, clay 8, lime 5 = 25.

For an assay of	4	troy ounces of ore -	or	1920 grains,
add	4	——— chalk	—	1920
	3	——— bottle glass	—	1440
	$0\frac{1}{4}$	——— charcoal	—	360
	$11\frac{1}{4}$			5640

And, lastly, let the second variety of this genus of iron-stone be supposed to contain, silex 10, lime 7, clay 5 = 22.

To	4 troy ounces of the ore	-	or	1920 grains,
add	$3\frac{1}{3}$ ———	chalk -	—	1680
	3 ———	bottle glass	—	1440
	$0\frac{1}{4}$ ———	charcoal	—	360
	$11\frac{1}{4}$			5400

Class of equalised mixtures, composed of, clay 7, lime 7, silex, 7 = 21.

To assay of this ore	4 troy ounces		or	1920 grains,
add	$3\frac{1}{3}$ ———	bottle glass	—	1680
	$2\frac{1}{3}$ ———	chalk	—	1200
	$0\frac{1}{4}$ ———	charcoal	—	240
	$10\frac{1}{4}$			5040

"Such are the proportions requisite to obtain, from all the various iron-stones, an accurate assay; the perfection of which is always indicated by the superior transparency of the flux, and the super-carbonation* of the metallic button. By scrupulously following these and similar proportions as the exigencies of the ore may point out, crude iron will always be obtained of the finest quality, carbonated beyond whatever is produced in the large way of manufacture, and its surface covered with a beautiful carburet of iron,† either in small shining specula, or in the state of a thin membrane. By a slight gradation of change in

* That is, containing a portion of carbon or pure charcoal *more* than sufficient to produce perfect malleable iron, but producing uniform fusible cast iron.

† By a carburet of iron, is meant, iron combined with a large proportion of pure charcoal, or carbon.

Malleable iron, is iron uncombined either with air or with carbon.

Blistered steel is iron with a small proportion of carbon.

Fusible, hard, cast steel, contains still more carbon.

Fusible smooth faced cast iron, still more than cast steel.

T. C.

the proportions of the component parts of the flux, the metal of the same iron-stone may be made to pass through all the inferior states.

Since, then, all iron-stones in the assay-furnace may be made to give out their iron at pleasure, of all the various qualities, it is surely erroneous to assert, that such and such iron-stones contain such and such qualities of iron; that this one affords metal of the finest quality, while that, on the contrary, yields iron fit only for forge-pigs or ballast; yet this is the universal language in the manufactory. In this, as in many instances, we accommodate the language to our ideas, rather than our ideas to truth. The suffrage of prevailing custom has imperceptibly associated with our ideas many absurdities which we are afterwards ashamed to acknowledge, and which darken the gleam of truth, or render it apparently ridiculous, merely because it is at varience with our prejudices. Where science guides not the manufacturer, or is scorned by him, his train of reasoning, though far from being just, is short; it is fitted to the narrow culture of his mind, and consonant to a barbarous nomenclature of received usage *.

* I cannot resist noticing one instance, prevalent at iron-works, of that blind reverence to the opinion of our predecessors, whose sources of knowledge must necessarily have been few and contracted. When super-carbonated crude iron is run from the furnace, it is frequently covered with a scurf, which when cold is found to be a coating of plumbago (carburet of iron) remarkably brilliant; sometimes in small specks, and at other times in large flakes: this substance is universally denominated *sulphur*, and, as the most expressive adjective for that quality, we say that the iron is *sulphury*. There are not, perhaps, two substances so opposite in their degrees of inflammability, or so widely different in their properties, as sulphur and plumbago; the existence of the latter almost wholly supposes a total absence of the former: yet, such is the want of investigation, or the slightest momentary reflection, that an indolent belief is passed as to the presence of a substance diametrically opposite to that which is expressed. *Sulphur* has hitherto been

In order to elucidate still farther how much the quality of the iron is dependent upon the proportions of the mixtures, in combination with or given to the ores, let a determinate quantity, say an ounce, of the oxyde of pure malleable iron be taken ;—this we are physically certain contains no mixture except oxygen existing in quantity proportioned to the stage of oxydation, the quantity being ascertained by its degree of obedience to the magnet ; when the quantity of oxygen given to it, by the decomposition of water, exceeds 25 *per cent.* few traces of magnetic attraction are perceptible :—introduce this oxyde into a covered crucible, without any addition, and expose it to a violent degree of heat for 40 minutes, (longer in proportion to the quantity,) a button of highly oxygenated crude iron will be obtained : if the heat is continued longer than is necessary to effect this, a small mass of malleable iron will be found occupying the bottom of the crucible. The produce in either case will be short of the real quantity of metal contained in the oxyde. When oxygenated crude iron is obtained, the ore from which it is produced, to use the common phraseology, is said to contain *bad iron.* That this has no relation to truth, will be seen by taking another portion of the same oxyde : let it be mixed either with chalk or lime, and a little bottle-glass, to constitute fusibility, and expose to a similar degree of heat with the former ; the whole contents in iron will then be found re-

the philosopher's stone of the iron manufactory ; to its presence is attributed the production of bad iron—when the metal is in its most valuable state, it is also *sulphury* ;—it prevents cast iron from becoming malleable, and if *sulphur* were altogether absent, hard or white cast iron could not be produced. If cast iron is found coloured, it is by the *sulphur* ; is it crystallised and coloured, then it has sulphur to excess ; should it have lost its strength, or have become loose in the fracture by an excess of shrinkage in large castings, still it is by the agency of sulphur : in short, in every process in the manufacturing of iron, sulphur explains the whole phenomena ! it is execrated in one process, and anxiously looked for in another.

vived, and occupying the bottom of the crucible in the state of fine carbonated crude iron. Here then is a complete alteration in the quality of the metal, though obtained from the same ore; for we cannot consider iron combined with oxygen, to which earthy bases are given, in any other light than that of an ore. Again, let a portion of mixture, exactly similar to the last, have added to it double or tripple its weight of bottle glass, and subject the whole to an equal heat with the former experiments, nearly a complete revival of all the metal will be found to have taken place; its quality, however, will be highly oxygenated and brittle. Such experiments clearly demonstrate, that the various qualities of crude iron are entirely owing to the mixtures in the ore, and their treatment; and that iron, considered as a simple metallic substance, is the same in point of quality in all ores.

If iron was originally formed in a metallic state, its property of decomposing water, whether casually exposed to a moist atmosphere, or removed at various depths from the surface, furnishes an hypothesis as to the primitive principle of iron ores; that part of the water—by far the greatest—which remained undecomposed, would serve as a medium, or vehicle of suspension, and conveyance to the oxyde; this again, in its turn, would be deposited either at the fountain-head, or at a greater or lesser distance from it, according to the affinities exerted upon it by other substances with which it might come in contact. Corresponding with this supposition, we commonly find those ores which are formed in vertical masses or knobs, approached by a great number of small veins occupying the smallest fissure or crevice in the rock. Time, and the re-action of additional water and acids, would a second time carry off a portion of the ore in chemical union; this, by the exertion of new affinities, would become precipitated, and mixed with the suspended earths, to form

regular strata of iron-stone. To such a primary and secondary agency of formation may be attributed the general superior richness of ores found in irregular vertical masses, to that of iron-stones. The same cause will also explain why more determinate qualities of iron are obtained from primitive ores, than from those of a secondary formation. In the former, the mixtures are commonly fewer, and the quality of the malleable iron more decided; in the latter, the quality of the metal is less certain, and more various, from the mixtures being more numerous. Hence we may also trace the reason of the superior qualities and marks possessed by some of the foreign fabrics over each other, where the same fuel has been used, and the same course of manufacture followed.

Having so far considered crude iron, in regard to its fusibility, and the facility with which it becomes changed into various degrees of carbonation or oxygenation, constituting a variety of qualities most pointedly distinguished in commerce, and in which the metallurgist discovers widely different properties and charateristic forms; I shall next proceed to mention in what manner strength may be given to any quality of crude iron which may probably be obtained by the fusion of an ore, and from what source this property is derived.

Upon a former occasion I have mentioned that iron, obtained from argillaceous ores, possessed a degree of strength beyond that obtained from the other genera. This truth daily presents itself to our observation in the large scale of manufacture; and however erroneous the reasoning of the manufacturer as to the cause, yet so evident are the consequences produced, that we must immediately attribute them to some source beyond the casualities of operation in the smelting furnace. In the explanation of this fact, as on the degrees of oxygenation and carbonation in general the manufacturer has recourse to the existent nature

of the iron in the ore, and denominates the metal contained in such and such an ore to be "strong, coarse, ill-melting iron;" or "weak, tender iron, possessing no body." That iron-stones and ores yield, in the operation of smelting, different qualities of crude iron, as to strength, is an undeniable fact; and that the same variety attaches to iron when converted to malleability is a truth daily evinced in our forges: yet these facts by no means entitle us to conclude, without farther investigation, that these varieties of strength are the hereditary property of the pristine formation of the metal. This inference accords with a hasty view of the matter, and a bare comprehension of effects, without tracing to its source the modifying principle of the whole. The theory which I have adopted, and which in every step I have found supported by numerous experiments, upon different scales, and by a long course of practical observation, explains to me, with much more ease and harmony, the whole phenomena of quality in ores and iron-stones.

To illustrate that part of my theory relative to strength, let the preceding experiment, wherein carbonated crude iron was produced from the oxyde of pure iron, be repeated with the addition of a little pure clay. If the clay added be half the weight of the lime also used, the iron will be found, when subjected to the gauge, much superior in strength; and if the experiment be accurately performed, the metal will be but a little reduced in point of carbonation. The following proportions will give accuracy to the result:—Oxyde of iron, 4 parts—Lime, 2—Clay, 1—Glass, 3 = 10 parts. By mixing clay with the flux in all experiments, the strength of the crude iron is improved. This point may be urged so far as to form, by an extra-addition of clay, a flux of difficult fusion; in which the iron becomes suspended in globules, which are partially malleabilised apart from each other. Crude iron,

obtained with a superior mixture of clay, in all its stages of quality, possesses a greater degree of strength than iron from calcareous iron-stones. Iron from argillaceous iron-stone is reckoned strongest when carbo-oxygenated; that extracted from calcareous iron-stone is reckoned to possess most strength when oxygenated, mottled.* I would far exceed the limits of the present communication, were I to enter fully into this curious subject, and particularise the different results obtained by the fusion of ores with different earths in various proportions: all my experiments have fully proved to me, that originally the quality of the iron, simply considered, was the same; that, as it underwent change by decomposition and new combination, it became united to foreign substances, possessing widely different properties; and which mixture, by a general fusion, imparts to the metal various properties, seldom homogeneous, but frequently otherwise: in short, that the numberless mixtures with which it is combined are not neutral in fusion, but convey an alteration to the quality of the reduced iron. I hope to resume this subject when my experiments will be more extended by the examination of a vast variety of iron-stones, and shall then point out the consequent effects of their application to the manufacture of cast and malleable iron.

The assaying of primary ores† comes next under consideration. These, I have already said, possess a much greater diversity of external character, as well as internal variety, than those of iron-stone. When assayed with a vitreous flux, either of salts, alkalies, or silex, the results are rendered very uncertain and erroneous: when pot-ash, tartar, &c. are used, the crucible is often destroyed, and the compound entirely lost: when bottle glass and a mixture of these are used, the scoria formed is so very black

* I cannot comprehend this. T. C.

† Ores found in primitive formations. T. C.

and ponderous as to give the most presumable indication of the secretion of metallic oxyde: this is afterwards verified by fusing the mass with a mixture of dried chalk and charcoal, a globule of metal will be obtained, which evinces the richness of the scoria; this, having lost its colouring principle (the metal), becomes clear and transparent. The results from these ores by fusion afford various products, and lead to different conclusions: I shall mention several of them.

The Cumberland iron ore, when introduced into a crucible without any additional mixture, fuses easily, and forms an opaque scoria, internally of a black colour, but towards the surface covered with fine shades of brown: this arises from a partial oxygenation of the semi-revived metal while cooling, and is often injured by a fresh combination of oxygen.* If the crucible remains sound, and the melted mass is kept in a state of extreme division for an hour, a considerable quantity of metal will be found precipitated, but so highly oxygenated as to shiver to pieces if exposed to air before it is entirely cooled. If, when the crucible is taken from the furnace, it be slightly inclined to one side, and the vitrified fluid entirely removed from the surface of the metal, a violent deflagration will immediately ensue, the ejected globules will be thrown three feet upwards from the mouth of the crucible: if the quantity of metal does not exceed 500 grains, it will totally disappear, except a rough dark-blue oxyde in the bottom of the crucible, not above 1-4th of the original weight. The metal thus oxydated* will be found in small spherules of a blackish colour, and spongy around the spot occupied by the crucible.

This curious appearance is in fact a combustion of iron by oxygen gas, furnished by the decomposition of atmospheric air: it is an operation which the accurate observer

* By being exposed to the atmosphere. T. C.

may daily see manifested in almost every department of the foundery and forge. By a just comprehension of it, and a proper appreciation of its effects, we have a key for the elucidation of the source and action of many facts long wrapped in mystery, or which have been explained upon principles destitute of stability, and unallied to the fundamental operations of truth.

In place of withdrawing the crucible immediately upon the separation of the crude iron, were it to remain for an hour longer under an inferior degree of heat, so as to consolidate the metal without again fusing it, then the whole mass would be found malleable; the scoria light and porous. In one of my experiments upon the hæmatites variety, I obtained from 1 lb. avoirdupois, or 7000 Troy grains, an ingot of fine malleable iron weighing 4486 grains; a produce equal to 64 *per cent.**

An oxygenating flux was however used, and nearly the whole contents in iron previously revived. In experiments without the addition of a flux, the transmutation from cast to malleable iron is shortened, but the produce is not more than 5-8ths of the intrinsic contents of the ore. Even this process may be considerably shortened by removing the covering of vitrified earths floating upon the surface of the metal: thus the small portion of the carbonaceous principle constituting fusibility is almost instantly carried off by the combination of oxygen; the metal loses its fluidity, becomes thick and clotted, and more speedily passes into the malleable state. In this process the quanti-

* This might be adduced as a proof that crude iron contains more parts congenial to malleability than is generally admitted, or than is manifested in the operation of converting it into malleable iron at the forge: the loss there has already been mentioned to amount to from 30 to 50 *per cent.* of real metal; in this assay, however, the produce in malleable iron was only 4,5 less than when accurately assayed, and rich carbonated crude iron was obtained; in which, too, the carbon constituted a part of the weight.

ty of malleable iron obtained is still less than in the two former: the surface of the metal being exposed by the removal of the scoria, oxydation takes immediate effect; and whilst malleability is pervading the under surface of the metallic button, the upper one becomes reduced to a blackish blue oxyde. Here a striking proof is afforded of the great affinity which oxygen has, in high temperatures, to heat or caloric. Were the surface of such highly oxygenated crude iron exposed, while fluid, to atmospheric air, at an ordinary medium, for 1-6th of the time, its whole metallic properties would be completely destroyed: in the present instance nearly one-half of the metal is preserved, although its surface is exposed to the action of a violent current of gas, (air) ignited to the highest pitch of whiteness*. In the proper assay of this ore I have

* I have frequently observed, in experiments with pretty deep crucibles, where the most violent heats were excited, and where the fluid metal had assumed a whitish-blue colour somewhat inclining to azure, that the quantity of oxyde formed was imperceptible, and never visible while the heat was continued of equal intensity; when this agent became less urgent, the surface of the metal became oxydated as usual. When a regulus of crude iron thus exposed was wished to be obtained free from oxydation, a little dry charcoal was introduced into the crucible so as to cover the regulus; this prevented the action of the air from taking effect while cooling, and preserved the button smooth. During such exposures, when no oxyde was produced, I have noted a loss of metallic parts equal to 5.7, or 10 *per cent.* when the space of time did not exceed one hour. Among several conjectures respecting the cause of this deficiency in weight, and real abstraction of metal, the two following have with me most veight. 1st, Either the metal deflagrates in small particles, which are thrown out of the crucible in sparkles, made invisible by the transcendent brightness of the surrounding heat: Or, 2d, that in consequence of the fluid metal being exposed to such a degree of heat, in contact with oxygenous gas, part of it becomes acidified, and forms the ferric acid.*

* This acid has never yet been shewn. T. C.

found all the varieties susceptible of various degrees of carbonation: for the most part I have used chalk and charcoal for the reduction of the ore into carbonated crude iron. In the hæmatites variety, for 1 lb. avoirdupois I have commonly added 6 oz. dried chalk* and 3-4ths oz. of charcoal; and for the splinty blue ore also a similar mixture. From both of these I have obtained the richest sort of crude iron. In the manufactory, these varieties are always reckoned to produce the hardest and most infusible qualities of crude iron: when the metal is subsequently manufactured into bars, it is stated at different places to produce cold and hot short iron.

The kidney ore will admit of a diminution of chalk, and a small addition of glass; 1 lb. avoirdupois of this variety will be accurately assayed with the addition of 5 oz. chalk, 1 oz. of glass, and 3-4ths oz. charcoal. The same proportion of mixtures will also accurately reduce the small pieces of this ore, commonly of a soft, greasy consistency, mixed with small fragments of the hæmatites and kidney, and will give out the iron which they contain super-carbonated. A mixture of this soft ore with kidney is preferred to the richer varieties at the iron manufactories. The Lancashire ore chiefly consists of this compound, and the poorer in iron has always a decided preference given it at the blast furnace.

The stratified iron ore of the island of Islay is of most difficult fusion when treated without any addition. It fuses into a blackish green ponderous mass, and, even exposed to the highest heats, lets fall but a small share of its iron. The quality thus obtained is in the highest degree oxygenated; its fracture is partially crystallised in lines which converge towards the upper surface of the button, similar in crystallisation to the fracture of zinc. A regulus thus obtained, when divested of its scoria, and pro-

* Instead of chalk, pure limestone or marble might be used. T. C

perly exposed to the action of the ignited gas, soon loses its fluidity, and passes into the state of strong malleable iron. If this operation is performed upon a large quantity, without agitating or turning the mass, the upper surface of malleable iron will early acquire the cold short quality, and will be subject, at the same time, to an uncommon waste by the rapid oxydation of its parts. In assaying this ore for the production of carbonated crude iron, the results are obtained with considerable difficulty; seldom perfect till the second or third experiment. This is chiefly owing to the great variety of quality in the stratum, two pieces seldom being alike either in appearance or in reality. The inferior masses yield from 44 to 48 *per cent;* and the superior qualities I have found as rich as 56 to 61 *per cent.* To obtain carbonated crude iron from the richest varieties of this ore, add to 1 avoirdupois lb. of it, 7 ounces of dried chalk, 3 of bottle-glass, and 1 of charcoal. This mixture will produce soft crude iron, possessing great strength, and an uncommonly large crystallised grain. The poorer qualities require an additional quantity of calcareous earth, to restore the equilibrium lost by the substitution of silex in place of iron. This ore had a trial in the large way at Clyde Iron Works, but was found to yield *bad* iron with the *usual* proportion of fuel.

Opposite in its quality and results is the Swedish ore of the island of Elba. This, when presented to a requisite proportion of carbonaceous matter, to take up its oxygen, not only clears itself of this hurtful mixture, but also takes up a considerable portion of carbon, which, in fusion, becomes united to the metal, and constitutes it perfectly carbonated. In experiments with this ore, I found that when 2 oz. of it were treated with 2 and a half oz. chalk, half an oz. bottle-glass and a quarter oz. charcoal, the mixture was with difficulty reduced to a white glass; which at no time had been sufficiently divided to allow a general gravitation

to the many globules of beautiful carbonated iron thus separated. In fusion, therefore, *per se*, the metal precipitated becomes greyish, and, in many instances, affords similar results to a pure calcareous iron-stone; with this principal difference, that it abounds with nearly a double quantity of metal, whose tendency to become carbonated is noways inferior to any iron-stone of that class. A smooth carbonated regulus will be obtained from this ore, by using the following proportions: Ore in a raw state, 2 ounces; chalk, 2 ounces; bottle-glass, 1 1-2 ounce; and charcoal, quarter oz. The scoria resulting from this fusion will be of a light-blue colour, clouded, and variegated like an agate, and very transparent. The great distance of Elba from this country precludes the possibility of using this ore in our manufactories with any profit, unless it could be brought home as ballast, and delivered in the vicinity of any iron-work at 22s. per ton. The products obtained from it in the assay-furnace, indicate, in an uncommon degree, how very valuable the quality of crude iron would be in the scale of manufacture, by its application.

The Norwegian, Danish, and Swedish ores, found in strata, resemble, in many points, the Scotch ore of the island of Islay; in assaying them a similar treatment is necessary. Some of them are more fusible, and afford singular qualities of crude iron. When fused with oxygenating fluxes, the metal produced is uncommonly hard and brittle; exhibiting a fracture studded with brilliant mirrors, diverging the light in small radii: even when fluxes are used, capable of conveying carbonation, the metal exhibits this bright granulated fracture in a great degree. One of the ores from the mine of Houban, upon being exposed a considerable time after separation, afforded a mass of pretty good steel. The proportions necessary to assay these, with accuracy, so intimately depend upon their richness, and the relative proportions of mix-

ture with which the iron is combined, that the same recipe can seldom be applied to more than one variety. As iron-stones are more defined, and their treatment prescribed by more certain rule, a knowledge of them will soon lead to a just comprehension of the primary ores; a second experiment, therefore, with any of them, will be sufficient to point out the necessary proportions for obtaining in the next assay carbonated crude iron. In one collection of Norwegian ores I found the following variety:—

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	
parts	18	21	35	47	55	63	iron
	17	16	19	11	24	19	volatile
	65	63	46	42	21	18	earths
	100	100	100	100	100	100	

This simple table will shew plainly how necessary it is to accommodate the flux to the variety of the ore. If from this collection you wish to obtain carbonated regulus, it is obvious that, in order to saturate them equally, the iron contained in No. 3 ought to be presented with double the quantity of carbon necessary to carbonate No. 1; No. 5 with a triple quantity; that of No. 6 with more than 3 and a half: and as I have proved that this effect will be chiefly produced with the use of a calcareous earth, it will at once be conceived how far this substance is to be used as the instrument of alteration.

In the recipes adduced in this and the preceding paper, I have always noted charcoal as a constituent of each mixture. Since I discovered that the *contact of calcareous earths conveyed carbonation to the metal, by the decomposition of the carbonic acid*, I have reduced the proportion of charcoal commonly used in the flux, and have, in the treatment of most iron-stones, even abandoned it altogether: however, as my experiments have not yet extended universally to primary ores, I have, in the mean time, retained it as a constituent part of the solvent.

The ore being thus analysed, it may be submitted to the common processes in the large way.

Roasting. If the ore on being pounded and exposed to a full red heat, gives out any sulphureous vapour, it should be roasted, by placing it in wedge-like heaps, and leaving openings for a fire. The ore thus roasted with a full red heat for 10 or 12 hours, will part with nearly all its sulphureous and watery parts. But unless it be stratified with charcoal dust, the current of air will oxygenate it, and render it still less metalline than before, and cause it to require a greater charge of charcoal, and a longer time in the smelting furnace. Mr. Mushet proposes roasting the ore in a separate furnace, but this would appear here, a plan too complicated.

The common method as detailed by Dr. Aikin, is as follows. 1 Chem. dict. 596.

The first process that the iron-stone undergoes after it has been broken into pieces not larger than an egg, is roasting. This is sometimes performed in cup-shaped kilns, the bottom being occupied by lighted coals and the kiln then filled up with ore, which by the time that the fuel is consumed is found to be sufficiently torrified. The most usual way however of burning iron-stones is the following. Upon an oblong piece of firm and level ground is laid a bed of small coal from four to eight inches in thickness; upon this is placed a stratum of iron-stone composed of pieces as nearly as possible of the same size, and from 18 inches to two feet thick: the upper surface of this is then rendered more compact by filling up the interstices with smaller pieces of ore. Upon this rests a layer of small coal not more than two inches thick, and on this as a base, is reared a gradually diminishing pile of ore so as to resemble the ridge of a house; finally, the whole external surface receives a compleat covering of small coals and coal dust. The pile is kindled by applying burning

coals to the lower stratum, which by degrees ignite the whole mass. The breadth of the pile at the bottom varies from 10 to 16 feet, the usual height is about five feet, and the length varies from 30 feet to 60 yards. When the coals are consumed the pile gradually cools, and in eight or ten days may be wheeled away to the furnace.

The ore if well roasted will now be of a reddish brown colour, of diminished specific gravity, and will have become magnetical: the sulphur, water, inflammable matter, and carbonic acid that it originally contained, will have been dissipated, and it is now ready to be smelted.

The following remarks and experiments by Mr. Mushet, throw great light on the theory of roasting, or torrefaction. 3 Phil. Mag. 200.

The burning or torrefying of iron-stones, known in the large way by the rather improper term of *calcination*, consists in exposing the stone to a certain degree of heat in contact with air, in order to dispel those substances which it contains, capable of assuming the aëriform state by the combination of caloric. This operation ought to be performed in a progressive heat, always short of fusion. The water is then slowly evaporated without being decomposed; the caloric unites to the carbonic acid, which soon assumes the gaseous state; and lastly, the sulphur, if any, sublimes.

This process is essentially necessary to be performed before the iron-stone is introduced into the blast-furnace. Were raw iron-stone, or ore, precipitated in the violent heat of the smelting-furnace, the water and acid would instantly be decomposed; the oxygen would partly unite to the iron in addition to the fixed quantity peculiar to each ore, and part of it would oxygenate the sulphur, either of the ore, or of the pit-coal, a portion of which is always present in the furnace. The whole mass would then be precipitated in fusion, and a dark porous lava obtained,

containing iron more difficult to be revived than ever, owing to the great quantity of oxygen combined with it. In cases of this kind, the disengaged hydrogen manifests its escape, by changing the colour of the flame from a mellow white to a pale sickly blue.

It must from all this appear obvious, that, when torrefaction has been properly conducted, a very considerable part by weight of the whole will be dissipated: the absence of these volatile substances always leaves the iron-stones more or less magnetic. The loss of weight, however, is very different in the various classes of iron-stones, even when they are all exposed for the same length of time to a degree of heat capable of expelling those mixtures, which, under such circumstances, assume the gaseous state.

1. Calcareous iron-stone, when properly exposed to torrefaction, loses more of its weight than either of the other two classes. Where the lime is abundant, I have found this iron-stone lose 38 per cent. but more commonly 35 and 36 per cent. of water, carbonic acid, and sulphur.

2. Argillaceous iron-stones, exposed to a similar degree of heat, and treated in the same manner, commonly lose in weight from 32 to 35 per cent.

3. Siliceous iron-stones always give out less weight when exposed to torrefaction under similar circumstances with other stones. In common they lose from 27 to 30 per cent. I have, though rarely, found them to give out 25 per cent. only.

The extreme loss of weight in each class must be considered as the utmost point to which torrefaction can with safety be urged, without exposing the iron-stone to an accumulation of weight by the combination of oxygen.

From the variously compounded natures of iron-stones arise the various calculations of the loss which they are said

to sustain in burning at different iron-works. Fields of iron-stone are commonly impressed with a general distinguishing characteristic feature: some are of the calcareous genus; some of the argillaceous; and others again have a more intimate alliance with silex than the former two. Hence we find, at those works where the chief supply is drawn from the argillaceous iron-stones, that the loss in torrefaction on the great scale is computed from 30 to 33 per cent. Where calcareous iron-stones form the chief supply, the loss is estimated at from 35 to 37 1-2 per cent. Few or no iron-works are obliged to have recourse to iron-stones abounding with sand for their chief consumption; a general estimation of the loss sustained by this stone in the large way is therefore difficult to be made, though, I have heard, that at some works 25 per cent. was all that was allowed to be expelled during burning. Nature has been extremely kind in the formation of our secondary ores of iron; as the bulk of them, that contain iron sufficient to entitle them to be smelted, are combined with superior proportions of clay and lime.

As the burning or torrefying of iron-stones is of great importance to the manufacturer, and as it may be in some respects gratifying to the man of science, I shall particularly enter into the various phenomena attending the operation; dividing torrefaction into two classes: that which deprives iron-stones of certain substances capable of becoming aëriform by the combination of caloric in contact with atmospheric air; and that which deprives ores of their oxygen—hence called de-oxygenation—by heating them in contact with charcoal, in closed vessels, or in cavities impervious to the external air.

1. The consequences of heating iron-stone exposed to air is a loss of water, sulphur, and carbonic acid*. A

* I have seen some iron-stones in torrefying deposit a beautiful oxyd upon their surface, of a lake colour, and light as down. The

small proportion of oxygen may at times be unfixed, when the fuel may chance to come into contact with the heated iron-stone under a partial exclusion from air. But the association of circumstances necessary to effect this can so seldom be the effect of chance, that it is never to be looked for with certainty. When the operation is properly performed, the last particle of acid and water may be expelled. But this point is difficult to be ascertained with any degree of exactitude: for, in proportion as these gaseous substances are carried off, the metal becomes more and more revived, of course more and more liable to attract, and fix oxygen by the decomposition of the ignited gas; and, as the last portions of the acid and water are distilling, the stone is apt to gain weight by the calcination (oxygenation) of its iron. This will positively be the case when the heat is carried beyond the necessary degree, and is indicated by the iron-stone swelling in bulk, becoming specifically lighter and porous on the surface, but gaining weight in a great degree internally. As oxygenation goes on, the magnetic virtue decreases, until at last it becomes entirely annihilated.

The first stage in torrefaction is indicated by the first general change of colour in the iron-stone. This is com-

same substance, I have observed, effloresced upon the surface of the fracture of highly oxygenated crude iron, which had been broken immediately after the metal had lost its fluidity. From this coincidence of effect, I am inclined to suppose, that the oxyd deposited on the iron-stone in burning, is the consequence of the decomposition of the sulphuric acid; a portion of which had been mineralised with the stone, holding iron in solution: and that in the latter it was occasioned by a superabundance of oxygen in the blast-furnace, probably from the introduction of raw iron-stone, which had escaped the effects of the fire: that the sulphur, as formerly stated, had become oxygenated, dissolving a portion of the metal; which was again deposited in the state of a calcined sulphat, when the acid was suffered to escape, by being freely exposed at a high degree of heat to open air.

monly a faded blood colour, more or less dark according to the quantity of lime present.

I have repeatedly made use of all the various iron-stones, in the state of a fine powder, in order to ascertain what was the weight lost by each class in its transition from its native hue to the first stage of an assumed colour. And I am enabled to state the following as an average of the results obtained on this head: Calcareous iron-stones give out six parts in one hundred of the raw mineral: argillaceous iron-stones, five; and siliceous iron-stones, four and a half.

If the pulverised iron-stone is thrown into a vessel red hot, this loss will be effected in two minutes. The change of colour is immediately effected on those parts in contact with the heated iron. The whole is brought into contact with it; and when thrown out, the magnet will be found to have acquired a perceptible influence over it. When the powder is first thrown in, a slight decripitating noise is heard for a few seconds. This operation may also serve to shew the presence of sulphur, or of its acid. When in the former state it instantly takes fire, and burns with a dark lambent flame. When the acid is present, it is easily known by the suffocating fumes disengaged by the action of heat.

The application of heat beyond the first stage of colour, causes the iron-stone to pass through a variety of shades. These, as in metallic substances, are the effects of the presence of air at certain degrees of heat*. As the progressive dissipation of the volatile mixtures takes effect, the colour deepens; and, according to the nature of the iron-

* From smooth-surfaced iron-stones and ores, when exposed to heat partially sheltered by charcoal dust from the action of air, I have obtained all the shades of colour peculiar to polished iron and steel; but with less of the metallic lustre, owing to the surface being more porous.

stone, becomes fixed, of a brown, dark brown, or deep claret colour. These indicate the almost entire expulsion of the water, acid, &c. In this state, all iron-stones are possessed of magnetic attraction, and exhibit the various phenomena already described, as being peculiar to their respective natures.

The methods commonly in use for torrefying iron-stone, in the large way, are of two different kinds: that of burning in kilns or conical furnaces; and that of exposing iron-stone in open air, stratified with coals, to combustion. The former is used in some places in Wales; the latter is almost universally adopted in England, and totally so in Scotland.

In the operation with furnaces, they become filled entirely with iron-stone, except a stratum of coals in the bottom, which is afterwards inflamed. The combustion is then carried on by means of a current of air passing through the furnace, and forcing the heat along with it. When the iron-stone is deemed sufficiently burnt, the register is shut up; and the combustion, no longer maintained by means of external air, soon dies away, and leaves the furnace to cool.

The most common method, however, of burning iron-stones consists in levelling a piece of ground, and covering it with a layer of small pit-coals. This is of various thicknesses, 4, 6, or 8 inches, according to the height the pile is to be built, and the nature of the iron-stone. Upon this stratum of coals the pieces of iron-stone are imbedded, as near to the same size as possible, in order that all may be equally acted upon. These are reared to various heights, 18, 20 to 24 inches, the determination of its height depending upon circumstances. The surface is a second time levelled, by introducing small pieces of iron-stone betwixt the interestices occasioned by the angles of the larger. This again receives a covering of small coals,

seldom exceeding 2 inches in thickness. Upon this is reared the subsequent building, always gradually narrowing itself till it has assumed the shape of a stout wedge, with its base resting upon the ground. After this is effected, the whole of the external surface receives a complete covering of the smallest sort of coals. The pile is kindled by applying burning coals to the ground stratum. This creeps slowly along; heats the stone upwards; kindles the second layer of small coals, and ultimately inflames the whole mass from top to bottom.

When the coals are consumed, the pile gradually cools, and in 8 or 10 days may be wheeled away to the furnace.

The quantity of iron-stone burnt at one time is various at different and even at the same places; some kinds require to be burnt in smaller heaps, owing to their nature and fusibility. At some works the fires extend from 50 to 60 yards; and it is not uncommon to see skilful workmen, at one end, adding fresh materials to the burning pile; while others, at the opposite end, are employed wheeling away that which the fire has left sufficiently burned for the purpose of the furnace. Fires that extend from 30 to 60 feet in length are more common; from 10 to 16 feet wide, and about 5 feet high.

At most iron-works a local opinion exists, to what degree of heat iron-stone ought to be exposed before it is properly fit for the blast-furnace. All, however, agree that burning is necessary; though few give an accurate reason why. The only one I have heard adduced is, that iron-stone is *calcined* in order to burn out the sulphur and other *heterogeneous* mixtures. Hence arise a diversity of opinions, chiefly founded upon individual notions of the fixity or volatility of sulphur. Some contend that sulphur is easily displaced, and that therefore the iron-stone should be moderately *calcined;* lest the sulphur from the coal used in burning it should enter, and again hurt the

quality of the iron. On the other hand, it is said that sulphur is of difficult expulsion from the centre of the stone, as it is never seen going off till a bright red heat forcibly expels it; and therefore it is highly requisite the iron-stone should be long and violently exposed till the last portion is got rid of. To effect this, therefore, the heat, say they, ought to be urged till such time as the stone has indicated signs of fusion, or has partially suffered thereby. In order to give strength to this opinion, those who adopt it add, that, by such severe *calcination*, the volume of stone is reduced, becomes heavier, and that it will consequently occupy less room in the blast-furnace; of course it is imagined that, bulk for bulk, the iron-stone becomes richer in iron than when in a raw state.

Those who are acquainted with the oxydation of metals, and the consequent increase of weight, will at once discover the source of this error, and readily conceive, that, after the metal in the iron-stone has become partially disengaged by the expulsion of water, carbon acid, sulphur, &c. forming frequently a third part of the whole weight, it will become an object of attack to the oxygen of the atmospheric air, the combination of which with the iron, alone adds to the actual increase of weight, and not the transposition of the particles of metal from one piece of iron-stone to another. It must also be obvious that, where such fallacious prejudices have taken root, the consequences must frequently be fatal to the interests of the manufacturer; as such iron-stones, literally calcined, must require an additional portion of fuel to furnish carbon to carry off the superadded oxygen.

It is somewhat remarkable that the phenomena attending the oxydation of iron should be entirely unknown at iron manufactories. Such a process is never dreamt of, and even the declaimers against severe torrefaction only account for the increase of weight, by asserting that the

earthy parts are burnt out and nearly consumed, and that the metallic parts only remain, destroyed however in their nature and *reduced to a cinder.*

We are not to wonder, therefore, at the uncertain results which the untutored manufacturer obtains, until such time as a long course of experience has taught him, that, by combining certain causes, good or bad effects are the consequence. Even at last he still rests upon an unstable basis; destitute of the correct operation of principle, and incapable of preventing an evil from a total ignorance of its real source of action, he can only in the end avoid it after a multiplicity of movements, wherein he finds his practical knowledge increased at the expence of a considerable sacrifice of property.

How much more enlightened would be the mind of the manufacturer, were he to attend minutely to the phenomena developed in all the stages of his process, and satisfy himself as to the radical principles of action in each individual stage! In doing this, chemical minuteness, the terror and butt of the unphilosophised mind, is not absolutely indispensible; and yet every thing may be ascertained necessary to be known for the production of certain determinate qualities of crude iron.

He would then easily comprehend that all iron-stones contain less or more water of crystallisation, and that, being combined with a certain proportion of lime neutralised with carbonic acid, it is necessary that they be exposed to a heat sufficient to expel the first and last of these as well as sulphur. The reason has already been given, and the consequence shall be once more stated. The evil effects produced by introducing raw iron-stones into the blast-furnace, are less owing to the small portion of sulphur contained in most of them, especially in balls, (the vapours of which arise even from the softest crude iron when fluid,) than to the decomposition of water and

acids, each of which gives up a proportion of oxygen to the metal chiefly before separation is effected.

Does it not then unquestionably follow, that if the quantity of charcoal in the furnace formerly was sufficient to take up the oxygen existing in the ore, and to afford carbonated crude-iron, that if a further quantity of this principle is added, by whatever means, part of the charcoal which formerly went to carbonate the iron now combines with the superadded oxygen to form carbonic acid; of course the metal will be deprived of its carbon, become white in the fracture, and may then justly be denominated oxygenated crude-iron. The same application to principle would also inform the merely practical man, that when iron-stone is completely deprived of those substances which assume the gaseous state by the combination of caloric at a moderate temperature, it is then sufficiently prepared for the furnace. This is always indicated by the colour which the stone assumes varying from a brown to a dark claret. Blues always succeed this shade; and the smallest appearance of blue, however light, is a certain sign that the external air has made an impression upon the particles of metal, by superoxygenating them. Instead therefore of expelling a further quantity of *heterogeneous* matter, a principle is added the most noxious and destructive to the existence of iron in a metallic form.

The phenomenon of iron-stone becoming heavier in the fire, would no longer be explained by assuming vague assertions incompatible with and inadmissible to common sense. Upon finding two pieces of iron-stone in the same fire, which have to appearance been affected in a widely different manner by the heat; the one heavy, of a black blueish colour; the other light and porous: the practical man would now no longer say that the metal from the porous piece had escaped by these pores, and entered into the ponderous one; and that the accumulation of

weight in the latter was entirely owing to it abstracting the metal from the former. Widely different indeed would be the conclusion. He now would have learned that metals are combustible bodies; that under certain circumstances iron is one of the most inflammable in the group; that, during its combustion, it decomposes the air that maintains the combustion, and fixes one of its elements in spite of the powerful affinity exerted upon it by the caloric; and that by this process alone it increases its volume and weight. The porous mass of iron-stone would now be described as having had its iron completely saturated with oxygen at a very high temperature; that an imperfect state of fusion had been the consequence; and that a combination of these circumstances, acting for a considerable length of time, had volatilised and carried off a very considerable portion of the metal.

On the same principle would be explained the increase of weight in the more ponderous piece; it would then readily be conceived, that the same association of circumstances had not been present; but that the iron had gained in weight by the addition of oxygen at a temperature short of fusing and volatilising the oxyd.

Having in the former part of this paper stated the average loss which the various natures of iron-stones sustain when exposed to torrefaction in external air, I shall now simply state the quantity of oxygen which the various classes are apt to imbibe when exposed to a high temperature, after those volatile mixtures capable of assuming the gaseous state by the combination of caloric have been expelled.

The facility with which iron-stones become oxydated is entirely dependent upon the nature of the mixture constituting fusibility or otherwise: so that were argillaceous, calcareous, and siliceous iron-stones, previously de-oxygenated, exposed to the same degree of heat—a degree

capable of oxydating their iron—the result would be, that the quantity of oxygen combined would be in a relative proportion to the fusibility of the mixtures, for a determinate space of time. The argillaceous iron-stone would be found in a given time to have gained least; the calcareous a larger portion; while the siliceous, containing an assemblage of mixture fusible at a degree of heat in which the former would remain unchanged, will be found to have gained the greatest weight; but if exposed to an high temperature for a sufficient length of time, the oxygen absorbed will be in an exact proportion to the iron contained in the stone; only, the siliceous iron-stones arrive soonest at a high pitch of combination. In the course of many experiments I have found the following proportions to be nearly just, when the quantity of iron contained in the respective stones was nearly analogous.

Argillaceous iron-stone, which has yielded me 38 per cent. in the assay-furnace, first distilled and afterwards carefully de-oxygenated, increased in weight, during an exposure to ignited gas for 8 hours in the bottom of a deep crucible, 22 per cent.

Calcareous iron-stone, which afforded a similar quantity of metal, and which was subjected to the same train of preparation, to dispel its volatile mixtures, and unfix its oxygen, gained in weight nearly 23 per cent.

Siliceous iron-stones, containing from 36 to 38 parts of iron in 100, treated in the same manner, afforded me instances of an accumulation of weight equal to 24 to 25 per cent.

In order more particularly to illustrate the double phenomenon of iron-stones first losing and then gaining weight, I shall insert the treatment of one particular stone of each class;- from which a positive judgment may be formed of the general operation, and results, peculiar to each.

1. There were introduced into an iron test some pieces of *argillaceous* iron-stones, weighing - 1750 grs.

After being exposed to a bright red heat for 8 hours, and then allowed to cool, they weighed 1160

Lost in simple distillation - - - 590 grs.

Equal to 33·6 per cent. Specific gravity in this state 2,52150.

The stone had now assumed a claret colour, and was possessed of regular internal fibres, adhesive to the tongue, obedient to the magnet, and exhibiting every property peculiar to excellent iron-stone.

I returned the residue, which, as above, weighed 1160 grs. and exposed it in an open crucible for 4 hours to an increasing heat till a slight degree of fusion was perceived to take place. This was indicated by the angles of the pieces becoming rounded, and swelling a little in bulk—When cool they were found slightly porous, and weighed - 1309

Increased in weight by the combination of oxygen - - - - - 149 grs.

Equal to 12.8 per cent. Specific gravity in this state 3·3636.

The fracture of the pieces now wore a semi-vitrified appearance, of a dark blue colour, inadhesive to the tongue, unmagnetic, but much more metallic and ponderous.

A *calcareous* iron-stone treatedafter the same manner, of which I also used small pieces, weighing . 1750 grs. which had yielded a similar product in iron in the assay-furnace with the former, when cool weighed - - - - - 1090

Lost in simple distillation equal to 37·7 per cent. - - - - - 660 grs.

The fracture of this iron-stone was now of a bright brown colour, streaked with lime, faintly marked with internal fibre, less tenacious to the tongue than the former class, but equally obedient to the magnet.

The residue, weighing as above - - 1090 grs. was returned to the furnace, and exposed in the bottom of a deep crucible, till such time as a slight indication of fusion was observed; when cooled, the pieces weighed - - - 1235

Gained in weight by the fixation of oxygen equal to 13·3 per cent. - - - 145 grs.

In its present state this iron-stone, in point of colour, resembled the former.

Its fracture, however, was smoother, and more vitrified, equally destitute of tenacity to the tongue, and obedience to the magnet.

3. An iron-stone, which contained a proportion of *siliceous sand*, was exposed under similar circumstances to the same degree of heat—quantity used 1750 grs.

When properly torrefied, weighed - 1248

Lost in simple distillation equal to 28·6 per cent. - - - - 502 grs.

The appearance which this stone had assumed was of a reddish, small, granulated fracture, considerably magnetic, but scarcely possessing any degree of adhesion to the tongue.

The residue, weighing as above - 1248 grs. was exposed to an equal degree of heat with the former classes, by which the stone suffered throughout a slight degree of fusion—when cool, the connected mass weighed - 1431

Gained in weight by the combination of oxygen equal to 14·6 - - - 183

The colour of the stone was now changed to a black, vitrescent, slightly porous mass, hard and refractory. I have not given the specific gravities of the two last natures of stones: iron-stones containing equal portions of iron, in similar states of preparation, vary little in their specific gravities.

It will no doubt be observed, that the increase of weight in these statements tally not with the sums formerly given: the amounts there adduced are results from iron-stones which had been previously deprived of most of their oxygen; but in these, the extra quantity of oxygen taken up by the stone is only given, forming an aggregate, with the original existing quantity, as shall hereafter be shown, nearly corresponding to the sums first given. From these experiments, singled out to convey a just idea of the changes to which iron stone may be subjected, it becomes obvious, that all the varieties of iron-stone are capable of decomposing atmospheric air at a certain temperature, and of fixing a portion of its oxygen, whereby weight is gained, by each, nearly equal to one-eighth of its original quantity.

It must also from this appear obvious, that the burning of iron-stone is an operation—though hitherto conducted by chance, exposed to all weathers—of the greatest nicety, and consequence, to the certain and economical manufacture of cast-iron; wherein a small addition of fuel, by exciting a high temperature, exposes the iron to the combination of a hurtful principle, in quantity (as will hereafter be shown) almost equal to what the metal was originally precipitated in. The extra proportion of fuel, therefore, requisite under circumstances where a severe mode of torrefaction is either universally adopted, or where it is frequently the result of inattention and want of skill, though as yet unascertained upon a large scale, must be very considerable.

I look upon it therefore to be a great desideratum in the preparation of iron-stone, to contrive a mode which would unite certainty and economy; a mode which would either de-oxygenate the ore unexposed to external air, or which would dissipate its volatile mixtures exposed to air, with a degree of certainty which, with a small share of attention, would preclude the possibility of the metal attracting more oxygen.

In the present mode of preparing iron-stones, too much is left to chance and the discretion of subordinate workmen. The surface of the piles, being always in contact with the open air, is frequently exposed to perforations from winds, especially in those parts where the layer of ignited coals comes in contact with the current: a hollow space is soon formed; the fuel, by means of the fresh air continually pouring in, becomes ignited to whiteness; the surrounding stone is immediately fused: should this aperture be joined by a similar communication from opposite sides of the fire, a degree of heat will be excited beyond what could have been conceived possible in this mode of burning, and oxygen be combined with a mass of stone in such an high proportion as to form a very considerable part of the whole weight. This is an accident which will take place even where order, regularity and experience are conspicuous; were it possible to avoid it by torrefying the iron-stone in that just temperature which has been formerly demonstrated as the most proper, uniting at the same time an equal degree of economy, it would contribute greatly to reduce to certainty and rule the operations of the smelting-furnace.

The extreme of fusing the materials and combining the iron with an extra portion of oxygen, is not the only evil which an accurate mode of torrefaction would avoid: the same train of casualty often affords a considerable portion of the stone not enough prepared, and some quite un-

touched by the fire. The effects produced by iron-stone in this state are exactly similar to those experienced in the former, arising from the same cause, but existing as the result of two opposite extremes.

I confess it is much easier to point out the faults of an established mode of practice, than to substitute one, which, though it might unite some superior advantages, yet might not combine an equal number upon an extended scale. I have frequently considered the subject, and have as often been impressed with the truth of its importance in the manufacturing of iron. At some future period I may submit to the manufacturers of iron a double method of preparing iron-stones for the blast-furnace; in which, certainty of operation would be obtained, and in the end most probably a degree of economy insured equal to that of the present mode.

I would effect this by exposing the iron-stone stratified with a small proportion of coals, in simply constructed ovens, entirely covered on the top, except a few small funnels to carry off the smoke and disengaged vapours; the ignition to be occasioned by a current of flame passing under a flue in the bottom of the furnace, and conveying combustion to the sub-stratified coals. As this operation could be conducted to a physical certainty by means of damping the furnace instantaneously, as soon as the vapour, &c. had ceased, or as soon as complete ignition had pervaded the contents, (the duration to be determined by the nature of the iron-stone,) the results in this case could at all times be depended upon, and the present irregular products avoided. A second method of depriving iron-stones of their volatile mixtures would be to expose them to a considerable degree of heat, in contact with the dust of pit-coal coaks—as being the most economical—shut up from the admission of external air. This would not only deprive them of their acid water, &c. but would also un-

fix most of the oxygen combined with the metal, and afford the iron nearly in a disengaged state. Both these methods, however, at the present time, want the sanction of approving practice, on an extensive scale, to render them useful, or worthy of universal attention.*

De-oxygenation of Iron-stones. This process has been long known in part, and its principles (so far as understood) applied by the metallurgist to deprive the ore, subjected to the assay-furnace, of its oxygen, in order that the metal might become revived. Its operation is however much more extensive than what has hitherto been conceived; and its results afford the most beautiful and interesting phenomena known in the art of manufacturing iron.

De-oxygenation in the case of iron-stones will admit of being divided into three distinct stages, all of which tend to the same final result.

1. That wherein iron-stone is found to have lost its water of crystallisation and continuity of fracture; to have assumed a greyish white colour, soft and pulverulent; and greatly specifically lighter than formerly, having lost from 2-5ths to 9-20ths of its original weight.

2. That stage wherein the pieces have assumed the state of malleability, and have again become firm and connected; wherein they brighten under the file; and, when subjected to the hammer, under various degrees of heat, receive impressions at pleasure, and draw into shape.

3. That stage wherein, by prolonging cementation, the pieces of iron-stone are found to have passed into the state of steel; possessing all its properties, though difficult to separate from the earthy parts, and preserve its quality; but which may be precipitated from the steelified ore by fusion, in the state of cast-steel, by means of the assay-furnace.

* This plan had been adopted, and *Jars* has given a plate of the oven. T. C.

These three distinct stages of de-oxygenation are produced by a continuation of the same cause to which all iron-stones may at pleasure be subjected. With primary ores, richer in iron, the results are more certain, ponderous, and much better suited to operate upon, for the production of good malleable iron and steel: these are almost universally capable of being de-oxygenated, for the production of both these modifications of the metal. I have met with no exception, indeed, but in the case of a few granulated Norwegian ores, a blue speckled Danish ore, a few Russian bog ores, and the Scotch ore of the island of Islay.

In the present paper I shall confine myself to a minute detail of the first stage of de-oxygenation; the second and third stages, as they more immediately belong to the manufacture of iron and steel, shall be fully considered in connection with this curious mode of manufacturing these states of the metal from ores without fusion, which, from its novelty and simplicity, deserves a thorough investigation of operation and principle.

De-oxygenation, by roasting, simply consists in exposing iron-stone or ore, stratified with coaly matter, such as the dust of pit-coal coaks, or the charcoal of wood unexposed to air, at a high temperature. The oxygen contained in the ore is taken up by the charcoal, and passed off in the state of carbonic acid; while the water, carbonic acid, &c. is evaporated by the heat. In proportion as the ore becomes cleared from these mixtures, the metal becomes more and more revived, approaching however to the state of malleable iron, though still interspersed with the original quantity of earthy parts united in the stone. By increasing the temperature, and continuing its duration, the particles of iron unite, and form themselves into fibres, which even when cold, may be twisted and bent a little; still however having the original quantity of earthy

matter almost invisibly interposed betwixt their interstices. If the heat is urged still further, the iron, now malleable, begins to take up a portion of the carbon from the charcoal, and the metal then commences its change toward steel.

During any part of the process, should air come in contact with the ore, by previously destroying the surrounding charcoal, an immediate oxydation of the iron takes effect, proportioned in its increase of weight to the stage of the operation at which it is effected. The ore has then passed into a friable, bulky, and unmetallic state.

In de-oxygenating iron-stones, with an intention of discovering and of establishing an analogy as to the quantity of oxygen contained in the respective classes of stones, I was frequently led to conclude, that argillaceous and calcareous iron-stones contained less oxygen than iron-stones where a greater proportion of silex predominated. Though by far the greater number of experiments performed on this subject were in favour of such an inference, yet I have at times experienced my arrangement palpably contradicted, without being able to solve the obtruding difficulty. I shall not however despair, in most cases, to reduce to certain invariable inherent properties, and external characteristic forms, the various iron-stones in the manner in which I have arranged them, and consonant to the results obtained from them in the process of manufacture. The utility of such an arrangement, founded upon experiment, must be obvious and striking: it will give certainty and value to the various products of the manufacturer, as it will in the end systematize the manufacture itself, and reduce it to rules guided by principle, and not by the aberration of a false or misinformed judgment.

From many experiments I have made with all the varieties of iron-stones found in this country, I shall subjoin the treatment of one of each class, highly marked with the predominating earths, that an accurate opinion may be formed of the phenomena exhibited in this part of the process.

I. I used a fine *argillaceous* iron-stone, in small pieces, weighing - - - - - - 1750 grs.

After a proper distillation of 8 hours in a degree of heat equal to 30° of Wedgewood*, I obtained a fine purple-coloured fibrated iron-stone, which, when cold, weighed - 1160

Loss of water, acid, and sulphur, equal to 33·6 per cent. - - - - 590 grs.

The influence which the magnet possessed over this stone was considerable; the adhesion to the tongue was however great.

I next introduced into a proper vessel, in contact with charcoal-dust, some pieces fractured from the same original mass; they also weighed - - 1750 grs.

After exposure for 14 hours to a degree of heat equal to 120° of Wedgewood, the iron-stone, being carefully separated from the charcoal and dried, weighed - - 1002

Loss of water, acid, sulphur, and oxygen 748 grs.
Lost by simple distillation - - 590

Oxygen taken up by the charcoal, equal to 9 parts in 100 - - - - 158 grs.

This must not, however, be taken as the total measure of oxygen combined with the iron, but only that portion taken up in the first stage of the operation; which, as it possesses the following properties, fully entitles it to this distinction:

1. The iron-stone, from being firm and compact, possessing specific gravity from 3 to 3·5, now becomes comparatively light, friable, and pulverulent; specific gravity, from 2·1 to 2·5. It now moulders with a slight pressure, and is easily reduced to fine powder of a whitish grey colour, which again possesses the following distinct proper-

* Wedgewood's pyrometer.

ties: It adheres to the magnet in the greatest abundance, but not in confused clusters like iron-stone simply torrefied or roasted: a manifest indication to become attached in the form of fibres is visible; and the quantity taken up is equal in point of bulk to the effect produced with iron filings.

2. Iron-stone in this state pulverised, when strewed in the flame of a fire or candle, gives out metallic sparks, like the combustion of iron-filings when strewed in the same manner. When the flame of the blow-pipe is directed upon it, a considerable inflammation takes place, and the metallic particles again become oxydated.

3. In this state, iron-stones possess the property of effervescing violently with the sulphuric and muriatic acids. The iron and lime are instantly dissolved, without the production of heat. This is only peculiar to iron-stones at this period of de-oxygenation. In no other state either raw or roasted, does iron-stone possess this property, unless highly united to lime; but remains undissolved till it has attracted a portion of the oxygen from the acid with which it is in contact.

From these confirming circumstances I conclude, that the particles of metal exist in a highly disengaged state; that they are partially malleable, yet so much combined with oxygen as to be easily precipitated, in fusion, for the production of cast-iron, with a sparing proportion of fuel, and a proper application of solvents. So far, therefore, as this experiment leads us, the practical analysis of this ore may be thus stated:

In the assay-furnace 100 parts of this iron-stone yielded a button of super-carbonated crude iron equal to - - - - 39·5 parts.

Water, carbonic acid, and sulphur, lost in simple distillation - - - 33·6

Oxygen taken up by the charcoal 9·0

In the subsequent part of the operation I found that, when the iron-stone had assumed malleability, and brightened under the file, a further quantity of oxygen was taken up, equal to - - 4·2—13·2

Clay, lime and silex united in the stone - 13·7

100 parts.

The earths I found to be proportioned nearly as follows: Clay 7 parts, calcareous earth 4, silex 2·7 = 13·7.

II. Of a *calcareous* iron-stone, reduced in the same manner, I operated upon - - - 1750 grs.

After being exposed to a similar distillation, I found it to weigh - - - - 1090

Lost in water, acid, and sulphur, equal to 37·7 per cent - - - - 660 grs.

This iron-stone, when torrefied, exhibited a thin schistus of calcareous plates: its fracture also presented calcareous lines running in various directions: its colour was reddish brown, partially fibrated, magnetic, and tenacious to the tongue.

I took of the same, mixed with charcoal dust, and exposed the vessel to a temperature equally high with the former. 1750 grs.

The residue, when carefully separated from the charcoal, washed and dried, weighed 922

828 grs.

Lost in simple distillation, as formerly shewn, 660

Oxygen taken up by the charcoal, equal to 9·6 parts in 100 - - - - 168 grs.

In this state the stone was pulverulent, much frittered, and of a darkish grey colour. Its fracture exhibited a number of white spots like madrepore. In many places

lime was distinctly perceived: when pulverised, it sparkled in the flame, dissolved rapidly in acids with a violent effervescence, was less magnetic than the former, though possessing a great tendency to adhere in the form of fibres. From this treatment the practical analysis of this stone will stand as follows:

In the assay furnace it yielded, of super-carbonated crude iron, per cent. - -	37·5 parts
Water, acid, and sulphur lost, as formerly shewn, - - -	37·7
Oxygen taken up in the first stage of de-oxygenation - - -	9·6
Afterwards taken up in cementing the iron-stone to render it malleable -	4·9—14·5
Clay, lime and silex - - -	10·3
	100 parts

By dissolution in acids, I found the earthy parts to be nearly as follows: Lime 5·2—Clay 3·1—Silex 2=10·3.

This analysis must not, however, be taken as a standard whereby the quantity of iron and earth is to be judged of in calcareous iron-stones in general. The iron-stones of this class, contain much less iron than argillaceous or even siliceous iron-stones; 28 to 32 per cent. are products more commonly met with than 37 and upwards; the difference in point of metal being made up in lime and clay. In stating the quantity of oxygen disengaged, I conceived it proper to adduce iron-stones, though of different classes, yet containing nearly the same weight of metal as the quantity either disengaged or absorbed must be in a direct ratio to the existing quantity of iron.

III. I operated with a *siliceous* iron-stone, weighing also - - - - 1750 grs. composed of small pieces, and exposed for the same length of time, and to the same

degree of heat as the former classes: the residue weighed - - - - - 1249

Lost in volatile matter by simple distillation, equal to 28·6 per cent. - - 501

In its present state the fracture of this iron-stone was reddish brown, studded with spiculæ of shining silex, slightly adhesive to the tongue, and considerably obedient to the magnet.

I next introduced into a crucible, stratified with charcoal-dust, some pieces of the same mass, weighing - - - - - 2374 grs. and exposed them to a degree of heat of equal intensity with the former; after the pieces were washed, and carefully dried, they weighed - - - - - - - 1343

Amount of water, acid, sulphur, and oxygen dissipated - - - - - 1031 grs.

Equal to - - 43·4 parts in 100

Lost in simple distillation as above - - - 28·6

Oxygen taken up - 14·8

This iron-stone was frittered, very magnetic, but dissolved less rapidly in acids, and with less effervescence; colour of the fracture light grey, and slightly spongy. The practical analysis of this siliceous iron-stone will therefore stand thus:

Carbonated crude iron obtained in the assay furnace - - - - - 36 parts.

Water, acid, and a considerable portion of sulphur - - - - - 28·6

Oxygen taken up as above - 14·8

Further, as will hereafter be shewn

in making the iron-stone pass into a state of malleability - - 2·5—17·3

Earths, viz. silex 9, lime 6, clay 3·1, = - 18·1

100 parts.

In these experiments I wished to obtain results which would throw light upon the de-oxygenation of iron-stones, with a view to apply them to practice upon an extended scale. I therefore used fresh ore, in order to present nearly the same surface to the action of the heat, and to be able to judge of the results apart from each other. In torrefaction, it frequently happens that the stone is reduced too small to enable us, by its subsequent treatment, to form a probable opinion of the tenacity, or otherwise, with which iron-stones hold their oxygen. The difference betwixt returning into the crucible the same pieces deprived of their volatile mixtures, and operating upon fresh ore, cannot be great, especially when they are selected from fragments of the same mass, directed by an intimate acquaintance and thorough knowledge of the qualities indicated by their external forms.

All iron-stones thus exposed to de-oxygenation become more or less saturated with carbon; it forms a union like carbon in steel, and its presence is only ascertained when the iron-stone is dissolved in an acid, by rising to the top, and forming a fine pellicle possessing lustre and various shades of colour. I have also at times detected crude carbon in the centre of pieces of ore one and a half inch diameter. To the remainder of this mixture, after the oxygen is taken up, ought to be attributed the natural tendency, which most malleable iron made in this process, has of becoming red-short.

The average of the results of the principal classes of iron-stones may serve for information on the products obtained, by treating those of equal quantities of mixture.

The analysis here furnished is not that of the chemist, or laboratory; but, though the calculations are less rigorous, yet they are sufficient for the manufacturer, and better suited for practical information; as they never once lose sight of their application and effects in the large way of manufacture, and as they have been chiefly effected by an agent, which alone, in the large way, can modify the whole, and procure results consonant to the use and existence of the metal.

From the amount of the experiments here recorded I would be apt to draw this conclusion, that, in general, iron-stones are variously combined with oxygen as to quantity: argillaceous iron-stone, least; calcareous, more; and siliceous iron-stones, most of all. *Mushet.*

In many places where the ore is too small to be conveniently roasted, it is washed to separate the dirt; but generally as I think, this washing is at the expence of a quantity of the yellow oxyd of iron which is at the same time washed away.

Of Fuel. Throughout the continent of Europe and America, the fuel is charcoal of wood. In Great Britain there were in the year 1806, 133 iron works at which 173 furnaces were in blast, producing annually 258,206 tons of iron. Of these, 11 iron works burnt the charcoal of wood; owing as I apprehend to the nature of the iron ore, such as the Cumberland and Lancashire ore, being what Mushet calls the primary iron ores. These 11 furnaces made annually 7800 tons of iron being on the average 709 tons per furnace. The other 122 works containing 162 furnaces in blast which were worked with the coak or charcoal of pitcoal, made annually 250,406 tons of iron, or 1546 tons per furnace; so that the furnaces worked with stone-coal produce annually in that country, more than twice as much iron as those worked with wood-coal.

Charcoal of wood, being almost the only fuel used for iron works or by blacksmiths in this country, the process of charring the wood is well known: but the following observations of Mr. Mushet, are worth attention.

Charred wood is almost universally used throughout the Continent, as fuel for the production of cast-iron. From its great abundance in the northern countries, the discovery of pit-coal would be deemed of little advantage for many years to come*. The extensive woods in Siberia and Sweden afford a constant .supply of fuel to the numerous iron works in those countries. The necessary regulations which the respective governments of each country have thought proper to enact, will in all probability preserve, during their existence, the necessary supply of fuel for the manufacturers†. If the woods receive necessary care and attention after the first cutting, they will replace themselves at periods from 15 to 18 years. The charcoal used in Siberia is all made from the pine and larch, the country affording no other varieties of timber. In Sweden, the manufacturers are supplied with a considerable proportion of harder woods, which is greatly in favour of the manufacture.

It has already been noticed, in a former paper, that the fuel used in Britain at an early period, and so far down as the beginning of the present century, chiefly consisted of wood. The kinds of wood used for this purpose were

* Pit-coal has been discovered in Siberia of various qualities and in great abundance, fit for the same purposes to which it is applied in this country.

† In Sweden there is a law restricting the manufacturers of iron to a certain annual produce; and this quantity is always in proportion to the ground attached to the work. In this manner the wood is enabled to replace itself at certain intervals; and each work is insured of an annual, though moderate supply. The more extensive and unpeopled tracts of Siberia, render such exactitude in the execution of the laws less necessary.

various; but char of hard wood, such as oak, birch, ash, &c. &c. was always preferred to that made from pine, holly, sallow, &c. &c. At the small remaining number of charcoal furnaces now in this country, the oak has still the undoubted preference. Its firmness and continuity enable it in the blast-furnace to support and convey principle to the iron contained in a larger portion of ore, than charcoal made from softer wood. The same properties also enable it for a time to sustain a heavier pressure of air from the discharging pipe: this facilitates the reduction of the whole, and greatly augments the weekly produce in iron. The mode of preparing charcoal of wood for the blast-furnace, though extremely simple, is yet capable of being greatly misunderstood, so as to occasion a considerable waste of wood in the process. The following is the detail of an operation which I have seen successfully tried, and which was productive of excellent charcoal. It is the same I believe as is followed at the two charcoal furnaces in Argyleshire.

First of all, a plot of ground is raised a little higher than the surrounding surface: this is made slightly convex. The burner commences by placing in the centre a circle of sticks, transversely inclining, and crossing each other near their tops. Around these are built successive circles of wood of various sizes, from 1 to 10 inches diameter; but care is always taken to place those of similar diameters in the same circle. A round of beams, of the largest nature, is immediately followed by one so much smaller as to fill up the interstices between the larger diameters, that no more air may be admitted than is necessary to excite gradual combustion. These are again followed by pieces of an increasing diameter. This mode of ranging the large and small sizes is continued till such time as the pile is deemed sufficiently large. The total width may then measure from 20 to 30 feet. The last

layer is commonly composed of small brush-wood. The whole is then covered with turf, the grassy side towards the wood; a coating of earth is then applied all round the bottom of the pile, and firmly beat to prevent the unnecessary admission of air. A small funnel, or opening on the top, is preserved by the transverse position of the first layer of wood; this is generally about 18 inches deep, into which the burning fuel is introduced. Combustion is in this manner first conveyed to the top of the pile, and is continued by feeding the small craters with pieces of wood for 4 or 5 days. When the interior part of the fire next the top is deemed sufficiently kindled and spread over the whole diameter, a row of holes is opened a few inches below, each about two inches diameter. The hole at the top is then entirely shut up, and the fire, now completely spread, slowly descends to where the air is admitted by means of the small apertures. When this is observed by the burner, which is known by the disappearance of smoke and vapour, they are immediately shut up, and a second row opened 6 or 8 inches under the first. In this manner the fire is conducted to the foundation of the pile, and the whole mass exposed to proper combustion. The intention of the operation is to bring the whole pile to a state of complete ignition, but in such a manner that no greater a portion of it may undergo combustion than is necessary to produce that effect. Hence the necessity for guarding against too free an access of air during the process. As soon as the operation is ended, which may last for 10 or 14 days, the whole is more closely covered up, and kept so till such time as the char is deemed sufficiently cool to be fit for drawing: it is then separated from the earth, and carrried away in bags or in waggons. Those pieces of wood not sufficiently charred are by the workmen called *brands*, and are commonly used for fuel to the next fire.

The loss of weight in charring wood is inconceivably great. In the large way it is almost impossible to ascertain it to any degree of exactness. The qualities of wood are so various, and the tendency which some have beyond others of parting with their juices, even when exposed to the same temperature, render it at best but a matter of uncertainty. I shall however insert a few which I have charred in the small way, and the results obtained from them; before weighing they were all exposed to the same temperature for a considerable time, and thoroughly dried.

It is however worthy of remark, that the produce in charcoal in the small way, does not give an invariable standard whereby to judge of that obtained on a large scale, where ignition is caused by the admission of external air into contact with the wood. In the large way the quantity of char afforded will depend more upon the hardness and compactness of the texture of wood, and the skill of the workman, than on the quantity of carbon it contains. In the following tables I have simply expressed the existence of the alkaline principle, in the various ashes obtained from the combustion of 1 pound of wood avoirdupois weight: this may be of use to those who wish to make experiments upon the formation of pot-ash. It will also be observed, that there are some woods that yield a much larger proportion of carbon than oak: these, however, are either too scarce or two valuable to be applied to the manufacturing of iron in this country.

*Table of the component parts of one English pound avoirdupois, or seven thousand Troy grains of the following varieties of Wood.**

	Water, Hyd. gas, Carb.acid	Carbon	Ashes	Colour and Degree of Saturation of the Alkaline Principle.
Oak - - -	5382,6	1587,8	29,6	Grey, sharply alkaline.
Ash - - -	5688,2	1258,0	53,8	Whitish blue, do.
Birch - - -	5650,2	1224,4	125,4	Brownish red, do.
Norway Pine	5630,9	1344,3	24,8	Brown, not in the least alkaline.
Mahogany - -	5147,0	1784,4	68,6	Grey, sharply alkaline.
Sycamore - -	5544,0	1381,4	74,6	Pure white, weakly, do.
Holly - -	5524,4	1394,3	81,3	Do. sharply, do.
Scotch Pine -	5816,7	1151,9	31,4	Brown, perceptibly do.
Beech - -	5537,3	1395,9	66,8	Greyish white, sharply do.
Elm - -	5576,6	1370,2	53,2	Grey, partially do.
Walnut - -	5496,5	1446,4	57,1	Pure white, light as down, weakly do.
American Maple	5553,2	1393,1	53,7	Dark grey, sharply do.
Do. Black Beech	5425,9	1301,8	72,3	Brown, do
Laburnum - -	5196,4	1721,0	82,6	White and grey, partially alkaline.
Lignum Vitæ -	5083,0	1880,0	35,0	Grey, sharply do.
Sallow - - -	5626,0	1294,8	79,2	Light grey, do.
Chesnut - -	5341,3	1629,6	29,1	Grey, do.

Parts in 100.

	Water, Hyd. gas, Carb.acid	Carbon	Ashes	Colour, Nature, Compactness of the Charcoal.
Oak - - -	76,895	22,682	0,423	Black, close and very firm.
Ash - - - -	81,260	17,972	0,768	Shining black, spongy, moderately firm.
Birch - - -	80,717	17,491	1,792	Velvet black, bulky and do.
Norway Pine -	80,441	19,204	0,355	Shining black, bulky and very soft.
Mahogany - -	73,528	25,492	0,980	Tinged with brown, spongy, and firm.
Sycamore - -	79,200	19,734	1,066	Fine black, bulky and moderately firm.
Holly - - -	78,920	19,918	1,162	Dull black, loose and bulky.
Scotch Pine -	83,095	16,456	0,449	Tinged with brown, bulky but pretty firm.
Beech - - -	79,104	19,941	0,955	Dull black, spongy, but very firm.
Elm - - - -	79,635	19,574	0,761	Fine black, moderately firm.
Walnut - -	78,521	20,663	0,816	Dull black, texture close, body firm.
American Maple	79,331	19,901	0,768	Dull black, texture close, moderately do.
Do. Black Beech	77,512	21,455	0,033	Fine black, compact & remarkably hard
Laburnum - -	74,234	24,586	1,180	Velvet black, do.
Lignum Vitæ -	72,643	26,857	0,500	Greyish, resembles pit coal, coaks, do.
Sallow - - -	80,371	18,497	1,132	Velvet black, bulky, loose and soft.
Chesnut - -	76,304	23,280	0,416	Glossy black, compact and firm.

* Dr. Watson 1 Essays, 132, says that 106lb.' of dry pealed oak, yielded 19 ounces of ashes: these ashes yielded 1 ounce and a quarter of saline matter. Hence 1 ton of potash requires about 1300 tons of dry, or about 1800 tons of green oak.

The advantages that charcoal possesses, beyond those of pit-coal, for the manufacturing of crude iron, are derived from the purity of its component parts, and the superior quantity of unalloyed carbon it affords to the iron. This principle is presented to the metal free from the combination of clay, lime, sand, and sulphur; with which pit-coal frequently abounds. A determinate quantity of charcoal by measure, will smelt and convey principle to three times the quantity of iron that can be done by the same measure of pit-coal coaks. Its greatest and most useful property, however, seems to be developed in the refinery fire, and similar bar-iron operations; where it manifests in the most evident manner its superiority over pit-coal, by shortening the tedious processes of the forge, diminishing the waste, and affording a much superior quality of iron for all the purposes of subsequent manufacture. Thus far Mushet.

Wood in charring loses somewhat of its bulk: by means of the heat applied, the acid moisture is distilled away, together with some part of the resinous and carbonic principle of the wood, but the woody fibres consisting chiefly of carbon or pure charcoal remain, and the vascular part now emptied of the fluid contents, form the pores of the charcoal. Of these Dr. Hook counted 150 in the eighteenth part of an inch in length; hence he concludes that in an inch square of charcoal there are 5,724,000 pores.

As there are great variations in the weight of wood, 1st. as to the kinds, 2dly. as to the time when it was cut, 3dly. as to the length of time it has been exposed to the atmosphere, 4thly. as to the part of the tree from which it is cut, no certainty can be obtained as to the proportion of charcoal by weight obtained from various woods: I think the charcoal according as it is well or ill burnt, varies from a third to a fifth of the weight of the dry wood from whence it was made.

In Pennsylvania a cord, (8 feet by 4 feet and by 4 feet, or 128 cubic feet of wood, put up as close as the sticks reasonably can be placed) of oak, will yield about 40 bushels of coal; a cord of pine, about 42 bushels: or it may be said that 100 bushels of wood coaled in the common way for the use of a furnace, will require two and a quarter cord of wood; but if coaled for a bloomery or refinery, where the coal must be all of the best quality, 100 bushels will require two and a half cord. The expence of cutting is about 40 cents a cord, coaling about 36 or 37 cents. From 20 to 40 cords of wood are coaled at once upon one hearth. The quantity of coal used to produce a ton of metal will of course vary with the nature of the iron ore, and the skill of the founder or manager. Mushet reckons 16 cwt. of charcoal of wood to a ton of metal; which I think is too little. In Pennsylvania I have heard it computed at 200 bushels, of about 14lb. to the bushel, of dry charcoal. There is no ascertaining any fact of this kind by weight; because, good well burnt charcoal will imbibe from the atmosphere in the course of 3 or 4 days, 12 or 13 per cent. of air and moisture: but on this calculation, the English (or rather the Scotch) managers make, a ton of iron with a fourth less coal than the American. Good charcoal should ring with a metalline sound: it will frequently strike fire with steel. Charcoal exposed to moisture, and kept together in great heaps, has been known to take fire spontaneously. I suspect charcoal is the worse for the moisture it imbibes; for in the heat of a furnace, the water will be decomposed both by the charcoal, and by the iron; and as water contains eighty-five and two thirds per cent. by weight of oxygen, and only fourteen and one third of hydrogen, it appears to me, that coal must be greatly wasted by moisture; but the subject is very difficult and complicated.

I have met with no calculations on which any reliance

can be placed of the time when an acre of ground from which the wood has been cut, will replace its original quantity: nor of the average cubic feet of wood on an acre. Mushet, conjectures these at 2000 cubic feet and 18 years; but the kind of wood, and the climate, and the soil, will make so much difference, that there is nothing like certainty. Pine in this country I imagine would replace itself in 16 years, chesnut in 12, oak in 20.

Of Pit-coal. The first intimation of the use of pit-coal for smelting, that I know of, is in Pryce's Mineralogy of Cornwall; but Becher early in the reign of Charles the 2nd proposed its use among the iron furnaces. The following brief history of its introduction is from Mushet, 7 Phil. Mag. 37.

The advantages which individuals derived from the manufacture of iron had induced many to engage in it. The business in point of extent seemed only limited to the supply of wood. New erections, for want of a proper supply of materials, became impracticable: those already engaged were more anxious to preserve their supply, however much circumscribed, than to listen to innovation, which, by substituting pit-coal for the charcoal of wood, would give to the new establishing manufacturer a great superiority in the market. It was also highly probable that many of the iron-works then established were at a considerable distance from pit-coal, the universal introduction of which would have proved fatal to their interests. Under such unfavourable circumstances, the discovery, or rather the practicability, of making pig-iron with pit-coal, we find announced by Simon Sturtevant, Esq. in the year 1612, who upon application, was favoured with a patent from king James for the exclusive manufacture of iron with pit-coal in all its branches for thirty-one years. In return, the said Simon Sturtevant bound himself to publish his discoveries, which afterwards appeared in quarto under the title of his *Metallica*.

It is uncertain from what reasons, but Mr. Sturtevant failed in the execution of his discoveries upon a large scale, and was obliged next year to render up his letters of monopoly.

The second adventurer in this line we find to have been John Ravenson, Esq. who, like Sturtevant, was successful in obtaining a patent for the new manufacture, but, like him also, was inadequate to the completion of it upon an extensive scale. Ravenson was also enjoined to publish his discoveries under the title of his *Metallica*, printed for Thomas Thorp, *anno* 1613. Several other adventurers stepped forth, all of whom had the mortification of resigning their patents without having contributed to the success of the arduous undertaking.

In 1619 Dudley obtained his patent, and declared, that although he made only at the rate of three tons of pig-iron weekly, he made it with profit. The discovery was perfected at his father's works at Pensent in Worcestershire. This gentleman's success in the various manufactures of iron with pit-coal had united not only all the proprietors of the charcoal iron trade, but many new adventurers, who wished to share in the emoluments of the new discovery. Their interest was so powerful as to limit Dudley's patent from 31 to 14 years. During the most of this period he continued to manufacture pig and bar-iron, and various castings, all of which he sold much lower than the charcoal manufacturers. In the article of castings alone, he must have had greatly the start of the charcoal foundries, as the quality of carbonated coak pig-iron is far superior to that of the charcoal iron of this country for the general purposes of casting.

The superior genius of Dudley was not always an object of passive indifference in the narrow estimation of the long established manufacturers. The envy occasioned by his uncommon success, produced at last a spirit of

combination, which terminated in a hostile attack upon his devoted works. His improved bellows, furnace, forge, &c. all fell a prey to a lawless banditti, betwixt whom and its furious leaders, no shades of distinction were visible, but those of avarice, ignorance, and the most contemptible prejudice.

To evade the mode of operation discovered by Dudley, or to introduce the making of pig-iron with pit-coal to greater advantage, a new plan was adopted by Captain Buck, Major Wildman, and others, in the forest of Dean, where they erected large air-furnaces, into which they introduced large clay pots, resembling those used at glass-houses, filled with various portions of the necessary mixture of ores and charcoal. The furnaces were heated by the flame of pit-coal, and it was expected that, by tapping the pots below, the separated materials would flow out. This rude process was found entirely impracticable; the heat was inadequate to perfect separation, the pots cracked, and in a short time the process was abandoned altogether.

The misfortunes which successively befel the unfortunate Dudley, arising from rivalship in the iron business, and his attachment to the royal cause during the civil wars, prevented his improvements from being closely followed up. The refusal of a new patent after the restoration prevented him from again entering into the business with his usual enterprise. From that period till about the year 1740, nothing of importance was done in the manufacture of coak pig-iron. The application of the steam-engine for raising and compressing air, no longer confined the manufacturer to local situations. Larger furnaces, with a proportionate quantity of blast, were introduced. Among the first effects, from 8 to 10 tons of pig-iron were produced weekly. Ever since, the weekly quantity has in general been increasing. The produce

being considerably dependent upon the quantity of air used for reduction, it is now so well understood, that at some works the blowing-machine is calculated to produce frequently 40 tons of melting pig-iron *per* week at each furnace. At some iron-works in Wales, where oxygenated crude iron is manufactured purposely for converting into bar-iron, there are several instances of a furnace producing 70, 71, and 72 tons of metal weekly. This astonishing quantity forms a most striking contrast with the early exertions of Dudley, who conceived three tons a profitable produce, and whose greatest exertions never exceeded 7 tons of pig-iron weekly.

After this slight sketch of the progress of manufacturing pig-iron with pit-coal, it may be gratifying to make a few observations upon the process conducted with the charcoal of wood. The superior purity of the carbonaceous matter in wood, and its greater degree of inflammability, render this operation more simple than that performed with pit-coal. The former properly admitted of a small furnace being used; and also required a much less degree of blast to purify the ore, and give out satisfactory results both in the quantity and quality of the metal. Few charcoal furnaces exceeded the height of 20 feet, and many of them were from 12 to 15. A very small column of blast was necessary to excite ignition, and produce the reduction of the materials. Lancashire and Cumberland ores were chiefly in use; their superior richness in iron rendering them soon metallised when in contact with ignited charcoal of wood: 12 to 24 hours were sufficient for this purpose, according to the size of the furnace and the quality of the pig-iron wished. Not so in the manufacturing of coak pig-iron at present: the inferior quantity of iron which is contained in iron-stones, the impurity of the carbonaceous matter in pit-coal, establishes a much less degree of affinity betwixt the metal and

the principle of its reduction. The oxygen of the iron-stone is longer in being removed: this requires an additional period of contact. To procure this, the furnace must be heightened to 35 or 40 feet, and the descent of the materials protracted to three days.

It will be proper to exhibit the comparative effects produced by the char of pit-coal and that of wood. The following particulars will serve as data to make a calculation of the relative effects of the two different fuels with a charcoal furnace of 26 or 27 feet high, 9 feet wide at the boshes, and blown by two inch and three quarter pipes placed along side of each other at the tuyere of the furnace. To make forge-pigs with this furnace, the following proportions have by experience been found requisite for each charge:

2 sacks of charcoal of 112lb. each -	224lb.
7 measures of well dried Lancashire ore, each 112lb.	784
Raw iron-stone - - - - -	56
Limestone - - - - - -	14

In 24 hours 18 of the above charges would have been consumed, and nearly 3 tons of forge-pigs produced.

The total quantity of char used for the quantity would be - - -	$2 \times 18 = 36$ cwt.
The total quantity of iron ore - -	$7 \times 18 = 126$
——————— of iron-stone -	$\frac{1}{2} \times 18 = 9$
——————— of limestone -	$\frac{1}{6} \times 18 = 2\frac{1}{2}$

We find therefore that 12 cwt. or 1344lb. of the charcoal of wood, produces of forge pig-iron 2240lb. or 1 ton; and that 126 cwt. of Lancashire ore + 9 cwt. of iron-stone, yielded of metal 60 cwt. This quantity, by an easy mode of calculation, will be found to be at the rate of 44·4 *per* cwt.

When carbonated crude iron was produced, the charge was, 200 cwt. of wood char, 5 cwt. of ore, 1-2 cwt. of iron-stone, 14 lb. of limestone.

The weekly quantity was always diminished in pro-

portion to the reduction of the quantity of ore used. In 24 hours the quantity of the pig-iron produced, averaged 48 cwt. of carbonated crude iron. As this is the quality of metal which serves as the basis of the calculation in Number XX. of the Philosophical Magazine, it will be the most proper standard to compare the widely different effects produced by wood and pit-coal. In that Number a table is given of the quantities of crude iron each variety of coaks produce, and which, for the sake of immediate comparison, I shall here again insert.

1 ton, or 2240lb. clod-coal coaks produces of carbonated iron - - -	1040lb.
1 ton, or 2240lb. splint-coal coaks -	840
——— 2240 mixed coals - -	702
1 ton, or 2240lb. of charcoal of wood, according to the proportions furnished above, will produce of carbonated iron	2986
1 ton, or 2240lb. of the same, will produce of oxygenated crude iron for forge-pigs - - - - -	3718; and
1 ton of carbonated pig-iron will require of the coaks of clod-coal - -	4824·6lb.
——————— splint-coal -	5973·3
——————— mixed - -	7147·5
——————— wood charcoal -	1680

From this comparative view it is found that charcoal of wood produces triple effects, or carbonates three times the quantity of crude iron that the clod-coal coaks do; three and a half times as much as the splint; and four and a half times as much as a mixture of free and splint.

The next consideration is the price of the two fuels. Charcoal of wood, about forty years ago, sold at 2*s*. 6*d*. *per* sack of 1 cwt. or 50*s*. *per* ton. 1 ton of good splint-coal coaks will be prepared on many of the present iron-work banks, labour included, at 11*s*. and at some places

so low as 10*s.* At present (1800) the price of charcoal is upwards of 4*l. per* ton. So that at this period, although the effects of wood are three and a half times those of splint-coal coaks, yet the price of one ton of charcoal wood will purchase eight tons of coaks; the quantity of the former limited to, and produced from, land which might be better applied to the purposes of agriculture; the latter found in immense fields, and in tracts of country which are always augmented in value by the developement of their mineral treasure.

A charcoal blast-furnace which smelts the whole year round, and occasionally makes forge-pigs and carbonated iron to the amount of 1000 tons annually, will consume 14,000 sacks of charcoal; which may be estimated at 1 cwt. *per* sack, or 700 tons, or 1,568,000lb. This divided by 18.75lb*. the pounds in a cubic foot, gives for the quantity of timber in cubical feet, 83.626. This is going upon a former calculation, and is supposing the wood to shrink but little during the process of charring. In the present state of the woods which are attached to iron-works, one acre will not yield more than 1200 cubical feet of timber. To ensure the annual supply, $\frac{83626}{1200} = 69.69$ acres of land would require every year to be cleared, or nearly 1400 acres would be requisite to form, with proper care, an unfailing source of supply; and at the rate of 4l. *per* ton, the fuel would cost 2,800l.

Let this be compared with a blast-furnace manufacturing the same quantity and quality of coak pig-iron. The average quantity for each ton will be nearly six tons of splint, or, as they lose 50 *per cent.* in charring, 3 tons of coaks × 1000 tons of pigs = 3000 tons of coaks, which at the highest price stated, 11s. *per* ton, amounts to 1,650l. or less than the charcoal, 1,150*l.* 6000 tons of splint-

* According to Watson, water being 1, dry oak is ,892. T. C.

coals will be easily procured from *one* acre of measurement where the stratum measures four and a half to five feet thick. An observation strikes us forcibly here, that, great as the consumption of wood is, a sufficient extent of country can from time to time replace any given quantity. No facts, however, which have hitherto come under our observation, warrant us to suppose the re-formation of pit-coal.

In preparing pit-coal for the blast furnace, well understood among manufacturers by the term *coaking*, flat surfaces are appropriated. These are firmly beat and puddled over with clay, so as to pass the necessary cartage without furrowing or loosening the earth. These spaces form squares, more or less oblong, and are called hearths; upon which the pieces of coal are regularly placed inclining to each other. Great care is taken to place each piece upon the ground layer on its acutest angle, in order that the least surface possible may come in contact with the ground. By this means, large interstices are preserved for the admission and regular communication of the air necessary to excite and effect complete ignition.

The quantity of coaks charred in one heap or hearth, is various at different, and even at the same works. Forty tons of coals is amongst the smallest fires, and some hearths again will admit of 80 or 100 tons. The length of the fire is in proportion to the quantity of coals built: the breadths and heights are also subject to no determinate standard; but are from 30 to 50 inches high, and from 9 to 16 feet broad. In building each fire, they reserve a number of vents reaching from top to bottom, into which the burning fuel is introduced. This is immediately covered by small pieces of coal beat hard into the aperture: these repress the kindling fire from ascending, and oblige it to seek a passage by creeping along the bottom, which is

most exposed to air. In this progress the fire of each vent meets, and, when united, rise gradually, and burst forth on all sides at once.

If the coal contains pyrites*, the combustion is allowed to continue a considerable time after the disappearance of smoke; the sulphur then becomes disengaged, and part of it is found in flowers upon the surface of the heap. If the coal is free from this hurtful mixture, the fire is covered up in a short time after the smoke disappears; beginning at the foundation, and proceeding gradually to the top.

The length of time necessary to produce good coaks depends upon the nature of the coal to be coaked, and the state of the weather. In 50, 60 to 70 hours the fire is generally completely covered over with the ashes of char formerly made: the coaks, thus entirely secluded from air, soon cool, and in 12 or 14 days may be drawn and wheeled to the furnace.

It is with pit-coal, in a great measure, as with wood, in the process of charring. Coals do not always afford a weight of coaks in proportion to the quantity of carbon in the coal. It depends more upon the capability of the coal to resist the waste occasioned by combustion, supported by external air, than upon the real quantity of carbon inherent in the coal; as may be seen by comparing the loss of weight which coals undergo in the large way, and the results obtained from the same coals, by burning them unexposed to external air in the small way.

The loss sustained in coaking coals fit for the purpose of manufacturing, or smelting iron, is found to be nearly as follows:

2240 pounds of free coals - yield 700lbs. coaks, loss 1540lbs.
2240 - - of splint and free coal mixt 840lbs. coaks, loss 1400lbs.
2240 - of splint slightly mixt yield 1000lbs. coaks, loss 1240lbs.
2240 - - of pure splint - - 1100 - - loss 1120lbs.

* Iron combined with sulphur. T. C.

This great weight thus lost is chiefly carried off in smoke. If a vessel is placed, filled with cold water, in the midst of one of these massy columns of vapour, before the fire has penetrated to the surface of the heap, a considerable quantity of tar will condense upon its external surface: this will continue to increase till such time as the water assumes the temperature of the smoke. At many iron works from 300 to 1000 tons of coals are thus weekly reduced to cinder. What a prodigious quantity of bituminous vapour, surcharged with tar, ammoniac and oil, must for the present be lost ! !† (Mushet.)

Pitcoal contains always an empyreumatic oil, moisture, carburetted hydrogen or coal gas, and ashes; and frequently sulphur. The quantity of oil, moisture, and gas can be ascertained by distillation; the quantity of incombustible matter or ashes, by burning the coal in contact with air; the quantity of saline matter in the ashes by lixiviation, filtration and evaporation. The quantity of combustible matter in coal, can be found out by reducing 100 grains into powder, also 100 grains of pure salt petre into powder: throw by small quantities (a grain or two) at a time, first the coal, and immediately after the salt petre into a red hot crucible. The salt petre will deflagrate while there is any inflammable matter to decompose it: when the deflagration ceases, the quantity of inflammable matter may be determined by the quantity of salt petre employed. Lampblack may be used as a standard, for it contains of ashes not more than one part in about 250. The ashes in coaks vary from 3 to 45 per cent. Hence it is manifest that the coal meant to be employed ought to be analysed before they are used; to ascertain 1st. what quantity of coak can be obtained from a certain weight of coal: 2ly. what quantity of ashes or incombustible mat-

† This is the basis of Lord Dundonald's patent for collecting coal tar. Becher as early as the reign of Ch. 1st. had suggested the propriety of saving these products. T. C.

ter the coaks contain: 3ly. what quantity of carbon they contain. Argillaceous and siliceous iron-stone require more fuel than the calcareous kind. Some calculations of Mushet tend to shew that upon the average of iron-stones when roasted, 1 cwt. of the stone will require 1 cwt. of well burnt coaks, and that every ton of iron produced, consumes upwards of 2 1-2 ton of good coaks, and 672,000 cubic feet of atmospheric air, at 300 cubic feet per lb. of Iron. 5 Ph. Mag. 366. Doubtless the wetter the ore is, and the damper the cinder is, the more coal is wasted. 1 lb. of well burnt coaks when laid in water, will take up nearly two ounces of water in an hour's time: this will require additional fuel to evaporate it; but that is not all; for as water contains so very large a proportion of its bulk of oxygen (upwards of 85 per cent.) it is manifest that this oxygen or the greater part of it, will combine with, and waste its due proportion of carbon or charcoal, and form carbonic acid gas, which requires in its formation 28 3-4 per cent. of carbon. I say the greater part of the oxygen of the water; because one part of it, will be employed in forming carburetted hydrogen with the hydrogen of the water, and burn away. Still the waste, as it seems to me, must be very great.

It is manifest also, that the heat given out is not (other things being equal) exactly in proportion to the quantity of carbon in the fuel. Thus, I have generally understood that the charcoal of oak gives more heat than the charcoal of pine, but by Mr. Kirwan's experiments the proportion of inflammable matter in pine charcoal, is beyond that of oak. Grains of charcoal necessary to alkalize 100 grains of nitre.

Charcoal.	*Specific gravity.*	*Number of grains.*
Of oak	,332	32½
Of birch	,542	22
Of pine	,280	24¼
Of fir	,441	27
Of pitcoal	,744	19

Coak Ovens. As the success of several manufactures depends on the procuring good coak, I feel pleasure in having it in my power to furnish a description of the kind of oven made use of in the north of England for coaking the refuse small-coal, which, before the adoption of this method, was entirely useless.

At the duke of Norfolk's colliery near Sheffield, several of these ovens are built on the side of a hill, occupying spaces formed within the bank. Each oven is a circular building, 10 feet in diameter within, and the floor laid with common brick set edgeways. The wall of the oven rises 19 inches perpendicular above the floor, and the whole is then covered with a brick arch which rises 3 feet 5 inches more, forming nearly a cone, whose base is 10 feet, and whose apex is 2 feet, if measured within. This opening of 2 feet at the top, is left for the convenience of supplying the oven with coal, and to serve as a chimney during the process. The whole height of the building from the floor is five feet, and the wall, which is 18 inches in thickness, is built with good brick, and closely laid, that no air may get in through any part of the work.

The floor is elevated three feet above the ground, for the convenience of placing a carriage under the door-way to receive the coak as it is raked from the oven. When the oven is thus finished, a strong perpendicular wall of common unhewn stone is thrown round it, of about 20 inches in thickness, and carried up the whole height of the oven, forming a complete square. The four corners between the circular building, and these outward walls, are then filled with soil or rubbish, and well rammed to give greater firmness to the work, and the more effectually to exclude atmospheric air.

When these ovens are once heated, the work goes on night and day without interruption, and without any further expense of fuel. It is conducted thus:—Small re-

fuse coal is thrown in at the circular opening on the top, sufficient to fill the oven up to the springing of the arch; it is then levelled with an iron rake, and the door-way built up with loose bricks. The heat which the oven acquires in the former operation is always sufficient of itself to light up the new charge; the combustion of which is accelerated by the atmospheric air that rushes in through the joints of the loose bricks in the doorway. In two or three hours the combustion gets to such a height, that they find it necessary to check the influx of atmospheric air: the doorway is therefore now plastered up with a mixture of wet soil and sand, except the *top* row of bricks, which is left unplastered all night. Next morning (when the charge has been in 24 hours) this is completely closed also; but the chimney remains open till the flame is gone, which is generally quite off in 12 hours more; a few loose stones are then laid on the top of the chimney, and closely covered up with a thick bed of sand or earth. All connexion with the atmosphere is now cut off, and in this situation the whole remains for 12 hours, to complete the operation. The doorway is then opened, and the coaks are raked out into wheelbarrows, to be carted way. The whole takes up 48 hours; and as soon as the coaks are removed, the ovens are again filled with coal for another burning. About 2 tons of coals are put in for each charge. These coaks are ponderous, extremely hard, of a light grey colour, and shine with metallic lustre. They are used in those manufactures that require an intense heat.

When coak is required to be more of the nature of charcoal, the process is conducted in a different manner. The small coal is thrown into a large receptacle similar to a baker's oven, previously brought to a red heat. Here the door is constantly open, and the heat of the oven is sufficient to dissipate all the bitumen of the coals, the dis-

engagement of which is promoted by frequently stirring with a long iron rake. The coak from these ovens, though made with the same kind of coal, is very different from that produced by the former operation; this being intensely black, very porous, and as light as pumice-stone. I am indebted to Mr. Curr, steward to his Grace the Duke of Norfolk, for these particulars, who very politely attended me through the works in the year 1802, and assisted me in taking the necessary measurements, &c. Parke's Chem. Cat. 4th ed. p. 443.

Dr. Watson (2 Essays, 318, et seq.) mentions the following results of a distillation of 90 ounces of Newcastle coal (bituminous) dry oak, box, mahogany and sallow wood.

Newcastle coal.		*oak.*	*box.*	*mahogany.*	*sallow.*	*produce.*
oz.	12	37¼	61½	33½	48	Liquid
	56	30	26½	27½	20½	Charcoal
	28	28¾	8	35	27½	Loss in air.

In all cases the nature of the liquid, of the charcoal, and the loss, is nearly alike. The liquid consists, 1st. of an oily matter swimming at the top: 2dly. of an acid watery fluid. In France, this liquor has been converted into vinegar, when procured from wood. Dr. Bollman, of Philadelphia, has succeeded in repeating the experiment. 3dly. a more heavy tenacious oil. The liquor procured from the distillation of pit-coal, has a stronger odour, is more empyreumatic than that from wood. The air in both cases, is carburetted hydrogen, or the modern coal gas. Four ounces of Liverpool coal yielded me 19 quarts of this gas; 4 oz. of fine saw dust, yielded somewhat above 12 quarts. These facts, with the additional ones of the manifest transition from perfect wood to perfect coal in the same piece, as I remember to have seen at Whitehaven, leave no doubt in my mind, of coal having been originally wood. The turpentine (or spirits of tur-

pentine) from coal tar, though offensive when smelt, has on that account a very beneficial effect against worms, when used for paying of the bottoms of ships.

Pit-coal, *usually* produces more than the same bulk of coak or cinder, when not over burnt; but the weight is greatly diminished: Dr. Watson had a ton of coal coaked in the usual way, and it weighed when cold, 11 cwt.*

The coak of pit-coal (that is, the charcoal of stone-coal) cannot as I think be well made unless out of bituminous coal, that burns with a flame and smoke and runs to a light grey-black cinder of a silvery lustre. This cinder yields greatly more heat than the charcoal of wood; for 14lb. of brass that took an hour and a quarter to be melted in a portable furnance with *charcoal*, was melted with *coak* in 48 minutes. But it is apt to run together, before it is entirely consumed by the supply of air. Hence among other reasons, in England, all the furnaces have gradually increased their blast.

I have thus dwelt upon pit-coal or stone-coal as a fuel, because I foresee the time approaching when this substance must be resorted to in Pennsylvania. Of stone-coal there are two principal varieties; 1st. Bituminous coal that may be converted into a coak cinder, which burns with smoke and flame and soot; 2dly. Anthracite, or coal that burns with a slight blue lambent flame, without smoke or soot, and which is gradually converted into a white ash as its surface consumes. The first kind is found at Chingleclamoose and Sinnamahoning on the west branch of Susquehanna, and abounds throughout the whole of Pennsylvania in a line directly west of those places, and north and south of that west line: Pittsburgh seems to be almost in the centre of the coal district.

The anthracite, or second kind of coal, is found on the head waters of the Lacawana and Lehigh that run into the

*I find by recent trial, that a bushel of pine charcoal weighs 14½lb: of oak 22lb. T. C.

north east branch of Susquehanna. It is found in almost the whole of the country watered by those two rivers and their tributary streams: Wilkesbarre is in the centre of a large district of this coal, which extends southward across the Berwick turnpike road, and subtends the whole clay state formation between Sunbury and Reading. It is found near the river five miles below Sunbury; it is found a mile from the turnpike road near the 21 mile stone from Sunbury to Reading, and it is found on the heads of Schuylkill. It is the same with the culm of Wales, and the smokeless coal of Kilkenny. I think there are coal strata, of one kind or other, throughout one third part of the whole state of Pennsylvania. The coal district of Potowmack I am not acquainted with; what I have mentioned, I have in a great measure personally traced. Considering the infinite importance of this substance as a fuel, I think I may venture to say, that nature has formed the greatest part of Pennsylvania for a manufacturing country.

Of the Blast Furnace. This furnace resembles *externally* a truncated quadrilateral pyramid of considerable height in proportion to its thickness: it is built of the strongest masonry, with contrivances by means of flues to obviate the danger of its cracking by the expansion that takes place when it is heated. The interior of the furnace consists of the five following parts, reckoning from the bottom upwards.

First the *hearth*, composed of a single block of quartz grit about two feet square: upon this is erected what in France and Germany is called the *crucible*, which is a four-sided cavity six feet six inches high, slightly enlarging upwards so as to be two feet six inches square at the top: the part above, called the *boshes* is in the shape of a funnel or inverted cone, eight feet in perpendicular height, and twelve feet in diameter at the top: this terminates in the

cavity of the furnace which is of a conical figure, thirty feet high, and three feet diameter at the top; from this part it enlarges into a funnel shaped *chimney* about eight feet high and sixteen in diameter at its mouth. The lining from the hearth to the top of the boshes is composed of large blocks of quartz grit, and that of the cavity of the furnace is formed of fire bricks 13 inches long, and three inches thick. About two feet above the hearth is a round aperture called the *Tuyere*, (Tweer) made in one of the sides of the crucible to admit the extremity of the blast pipe, through which the air in a high state of compression is forced into the furnace; and at the bottom of the crucible is an aperture through which the scoriæ and melted metal are from time to time discharged. A furnace of this construction, if it meets with no accident, may be kept in constant work for three years or more, without requiring any repairs.

The furnace is charged at the chimney by regular intervals with coak, iron ore, and limestone in the proportion of about 4 of the first, 3 1-3 of the second, and 1 of the third, by weight, care being taken so to regulate the frequency of the charges, as that the furnace shall be always full nearly to the top of the great cavity. The density of the blast and the form of the discharging pipe are ordered so that the chief focus of heat is about the bottom of the boshes; hence the ore has to descend about 38 feet perpendicular, before it arrives at the place where the fusion is effected. This does not happen in less than 48 hours, so that the ore is all this time in a state of cementation at a high temperature in contact with the burning fuel, and in consequence is almost saturated with carbon when it reaches the hottest part of the furnace. Being arrived at this place, the limestone flux, and the earthy particles of the coaks and ore run down into a slag, the iron is also melted and more or less decarbonized, and in part oxyda-

Modern English Iron Smelting Furnace.

Fig. 3.

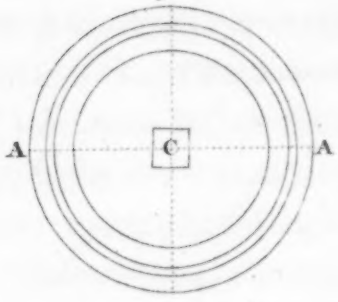


Fig. 4.

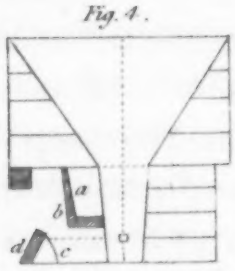


Fig. 1.

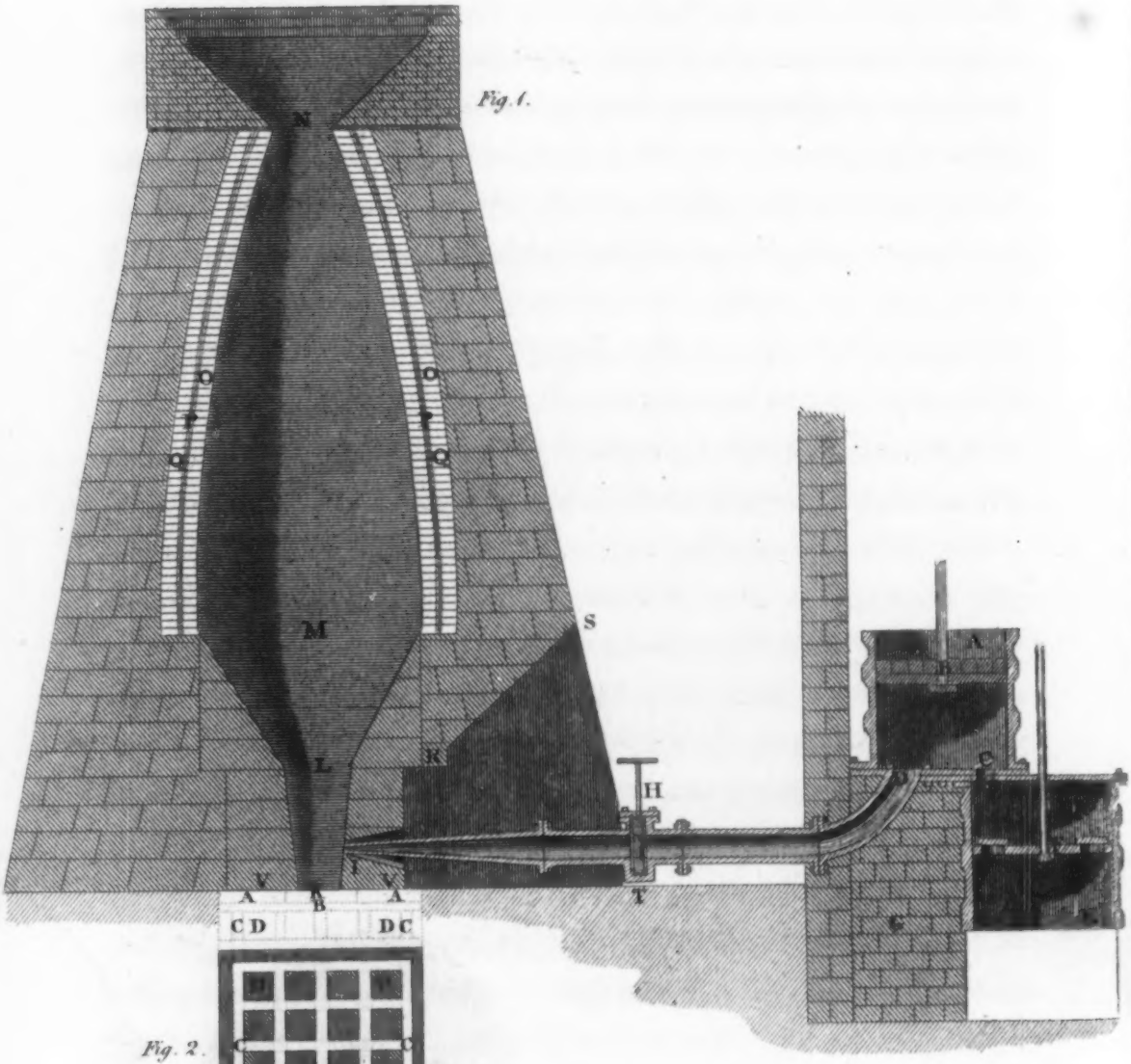
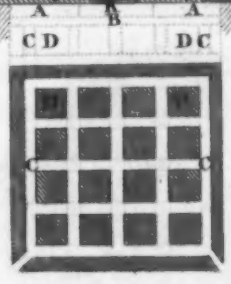


Fig. 2.



C. Tiebout sc.

ted by the blast inversely according to the proportion of fuel with which it is mixed (for the oxygen of the air by preference unites with the loose carbon of the coaks, rather than with that which has combined with the iron). The fluid mass soon sinks down below the influence of the blast, and while it remains in quiet at the bottom of the furnace the globules of iron are precipitated from the slag in which they were enveloped, and occupy the lowest place, while the covering of scoriæ thus interposed between the metal and that portion of the blast which is reflected downwards, prevents it from suffering any further loss of carbon. In proportion as the melted matter accumulates, the Sag being the uppermost, flows out at the aperture made for this purpose, and the iron is let out at regular intervals into furrows made in sand, where it forms what is called pig iron, or into a large reservoir whence it is poured by means of ladles into moulds, forming all the various articles of cast iron ware, from cannons and steam engine cylinders, to fire grates and common iron pots. (Aikins.)

Figure 1, (Plate 1.) represents a blast-furnace, with part of the blowing-machine. (Mushet.)

A, the regulating cylinder, eight feet diameter and eight feet high.—B, the floating piston, loaded with weights proportionate to the power of the machine.—C, the valve, by which the air is passed from the pumping cylinder into the regulator: its length 26 inches, and breadth 11 inches. —D, the aperture by which the blast is forced into the furnace. Diameter of this range of pipes 18 inches. The wider these pipes can with conveniency be used, the less is the friction, and the more powerful are the effects of the blast.—E, the blowing or pumping cylinder, six feet diameter, nine feet high: travel of the piston in this cylinder from five to seven feet *per* stroke.—F, the blowing piston, and a view of one of the valves, of which there are sometimes two, and sometimes four, distributed over the sur-

face of the piston. The area of each is proportioned to the number of valves: commonly they are 12 to 16 inches.—G, a pile of solid stone building, on which the regulating cylinder rests, and to which the flanch and tilts of the blowing cylinder are attached.—H, the safety-valve, or cock: by the simple turning of which the blast may be admitted to, or shut off from the furnace, and passed off to a collateral tube on the opposite side.—I, the tuyere, by which the blast enters the furnace. The end of the tapered pipe, which approaches the tuyere, receives small pipes of various diameters, from two to three inches, called *nose pipes*. These are applied at pleasure, and as the strength and velocity of the blast may require.—K, the bottom of the hearth, two feet square.—L, the top of the hearth, two feet six inches square.—KL, the height of the hearth, six feet six inches.—L, is also the bottom of the boshes, which here terminate of the same size as the top of the hearth; only the former are round, and the later square.—M, the top of the boshes, 12 feet diameter and eight feet of perpendicular height.—N, the top of the furnace, at which the materials are charged; commonly three feet diameter.—MN, the internal cavity of the furnace from the top of the boshes upwards, 30 feet high.—NK, total height of the internal parts of the furnace, 44 1-2 feet.—OO, the lining. This is done in the nicest manner with fire bricks made on purpose, 13 inches long and three inches thick.—PP, a vacancy which is left all round the outside of the first lining, three inches broad, and which is beat full of coak-dust. This space is allowed for any expansion which might take place in consequence of the swelling of the materials by heat when descending to the bottom of the furnace.—QQ, the second lining, similar to the first.—R, a cast iron lintel, on which the bottom of the arch is supported.—RS, the rise of the arch.—ST, height of the arch; on the outside 14 feet, and 18

feet wide.—VV, the extremes of the hearth, ten feet square. This and the bosh stones are always made from a coarse gritted freestone, whose fracture presents large rounded grains of quartz, connected by means of a cement less pure.

Figure 2 represents the foundation of the furnace, and a full view of the manner in which the false bottom is constructed.

AA, the bottom stones of the hearth. B, stratum of bedding sand. CC, passages by which the vapour, which may be generated from the damps, are passed off. DD, pillars of brick. The letters in the horizontal view, of the same figure, correspond to similar letters in the dotted elevation.

Figure 3, AA, horizontal section of the diameter of the boshes, the lining and vacancy for stuffing at M. C, view of the top of the hearth at L.

Figure 4, vertical side-section of the hearth and boshes; shewing the tymp and dam-stones, and the tymp dam-plates. *a*, the tymp-stone. *b*, the tymp-plate, which is wedged firmly to the stone, to keep it firm in case of splitting by the great heat.—*c*, dam-stone, which occupies the whole breadth of the bottom of the hearth, excepting about six inches, which, when the furnace is at work is filled every cast with strong sand. This stone is surmounted by an iron plate of considerable thickness, and of a peculiar shape, *d*, and from this called the dam-plate. The top of the dam-stone and plate is two, three, or four inches under the level of the tuyere hole. The space betwixt the bottom of the tymp and the dotted line is also rammed full of strong sand, and sometimes fire-clay. This is called the tymp-stopping, and prevents any part of the blast from being unnecessarily expended.

The square of the base of this blast-furnace is 38 feet; the extreme height from the false bottom to the top of the crater is 55 feet.

The furnace being finished, the bottom and sides of it, for two feet up the square funnel, receive a lining of common bricks upon edge, to prevent the stone from shivering or mouldering when the fire comes in contact with it. On the front of the furnace is erected a temporary fire-place, about four feet long, into the bottom of which are laid corresponding bars. The side-walls are made so high as to reach the under surface of the tymp-stone; excepting a small space, which afterwards receives an iron plate of one and a half inch thickness, by way of a cover: this also preserves the tymp-stone from any injury it might sustain by being in contact with the flame. A fire is now kindled upon the bars, and is fed occasionally with small coals. As the whole cavity of the furnace serves as a chimney for this fire, the draught in consequence is violent, and the body of heat carried up is very considerable. In the course of three weeks the furnace will thus become entirely free from damp, and fit for the reception of the materials: when this is judged proper the fire-place is removed, but the interior bricks are allowed to remain till the operation of blowing commences. Some loose fuel is then thrown upon the bottom of the furnace, and a few baskets of coaks are introduced; these are allowed to become thoroughly ignited before more are added. In this manner the furnace is gradually filled; sometimes entirely full, and at other times five-eigths or three-fourths full. The number of baskets full depend entirely upon the size of the furnace: that in the plate will contain 900 baskets. If the coal is splint, the weight of each basket-full will be nearly 110lb. × 900 = 99,000lb. coaks. As this quality of coaks is made with a loss of nearly 50 *per cent.* the original weight in raw coals will be equal to 198,000lb. When we reflect that this vast body of ignited matter is replaced every third day, when the furnace is properly at work, a notion may be formed of the im-

mense quantity of materials requisite, as also the consequent industry exerted to supply one or more furnaces for the space of one year.

When the furnace is sufficiently heated throughout, specific quantities of coak, iron-stone, and blast-furnace cinders are added: these are called charges. The coaks are commonly filled in baskets, which, at all the various iron-works, are nearly of a size. The weight of a basket, however, depends entirely upon the nature and quality of the coal, being from 70 to 112lb. each.* The iron-stone is filled into boxes, which, when moderately heaped, contain 56lb. of torrefied iron-stone; they often exceed this when the stone has been severely roasted. The first charges which a furnace receives, contain but a small proportion of iron-stone to the weight of coaks: this is afterwards increased to a full burden, which is commonly 4 baskets coaks, 320lb.; 2 boxes iron-stone, 112lb.; 1 box blast-furnace cinders, 60 or 70lb.† At new works, where these cinders cannot be obtained, a similar quantity of limestone is used.

The descent of the charge, or burden, is facilitated by opening the furnace below two or three times a day, throwing out the cold cinders, and admitting, for an hour at a time, a body of fresh air. This operation is repeated till the approach of the iron-stone and cinder, which is

* This same variety in the coal renders it almost impossible, under one description, to give a just idea of the proportions used at various blast-furnaces: to avoid being too diffuse, I shall confine my description connected with a coal of a medium quality, or a mixture of splint and free-coal, a basket of which will weigh from 78lb. to 84lb.

† A preference at first is always given to blast-furnace cinders in place of lime; being already vitrified, they are of much easier fusion, and tend to preserve the surface of the hearth by glazing it over with a black vitrid crust.

always announced by a partial fusion, and the dropping of lava through the iron-bars, introduced to support the incumbent materials while those on the bottom are carried away. The filling above is regularly continued, and when the furnace at the top has acquired a considerable degree of heat, it is then judged time to introduce the blast; the preparations necessary for which are the following:

The dam-stone is laid in its place firmly imbedded in fire-clay; the dam-plate is again imbedded on this with the same cement, and is subject to the same inclination, on the top of this plate is a slight depression, of a curved form, towards that side farthest distant from the blast, for the purpose of concentrating the scoria, and allowing it to flow off in a connected stream, as it tends to surmount the level of the dam. From this notch to the level of the floor a declivity of brick-work is erected, down which the scoria of the furnace flows in large quantities. The opening betwixt the dam and side-walls of the furnace, called the *fauld*, is then built up with sand, the loose bricks are removed, and the furnace bottom is covered with powdered lime or charcoal-dust. The ignited coaks are now allowed to fall down, and are brought forward with iron-bars nearly to a level with the dam. The space between the surface of the coaks and the bottom of the tymp-plate is next rammed hard with strong binding sand; and these coaks, which are exposed on the outside, are covered with coak-dust. These precautions being taken, the tuyere-hole is then opened and lined with a soft mixture of fire-clay and loam: the blast is commonly introduced into the furnace at first with a small discharging-pipe, which is afterwards increased as occasion may require. In two hours after blowing, a considerable quantity of lava will be accumulated; iron bars are then introduced, and perforations, made in the compressed matter at the bottom of the furnace; the lava is admitted to all parts of the hearth,

and soon thoroughly heats and glazes the surfaces of the fire-stone. Shortly after this it rises to a level with the notch in the dam-plate, and by its own accumulation, together with the forcible action of the blast, it flows over. Its colour is at first black; its fracture dense, and very ponderous; the form it assumes in running off is flat and branched, sometimes in long streams, and at other times less extensive. If the preparation has been well conducted, the colour of the cinder will soon change to white; and the metal, which in the state of an oxyde formerly coloured it, will be left in a disengaged state in the furnace. When the metal has risen nearly to a level with the dam, it is then let out by cutting away the hardened loam of the fauld, and conveyed by a channel, made in sand, to its proper destination; the principal channel, or runner, is called the *sow*, the lateral moulds are called the *pigs*.

In six days after the commencement of blowing, the furnace ought to have *wrought herself clear*, and have acquired capacity sufficient to contain from 5000 to 7000 weight of iron. The quality ought also to be richly carbonated, so as to be of value and estimation in the pig-market. At this period, with a quality of coal as formerly mentioned, the charge will have increased to the following proportions:—5 baskets coaks, 400lb.; 6 boxes iron-stone, 336lb.; 1 box limestone, 100lb. (Mushet.)

In 1 Repertory of Arts, old series, is Mr. John Wilkinson's patent for a small furnace for smelting iron, but I have not heard that it was ever adopted.

The articles, Blast, Blow, Furnace and Iron, in Rees's new Encyclopædia, are well drawn up, mostly from the same sources that I have resorted to. As I have made little or no use of those articles, I refer to them here as worth perusing.

The next plate, is the ground plan and outlines of the furnace commonly used in Pennsylvania. The plate it-

self is sufficiently intelligible, but the following remarks may be usefully added.

Ground plan of the furnace 30 feet square.

Height from the ground 38 feet.

Height from where the boshes begin to slant 26 feet.

Width at the level of the platform of the boshes 9 feet.

From the hearth to the bottom of the boshes 5 feet.

From the hearth to the bottom of the tympan 1-4.

Declination of the wall, from the bottom of the boshes upwards 9 inches per foot.

Furnace hole 21 inches at top, 19 inches at bottom, and three eighths deep.

The wall above the point of the arches, is supported by cross bars of thick iron.

The dam 11 inches high, leaving 5 inches open from the top of the dam to the bottom of the tympan.

The hearth is bedded on 15 inches of dry sand.

Opening of the chimney at top 18 inches: too small.

Some of the vacancies left in the walls to let out the steam (flues of 6 inches square) are shewn on the plan: they may be filled up with coarse loose stone.

Water wheel 30 feet.

Length of shaft 33 feet.

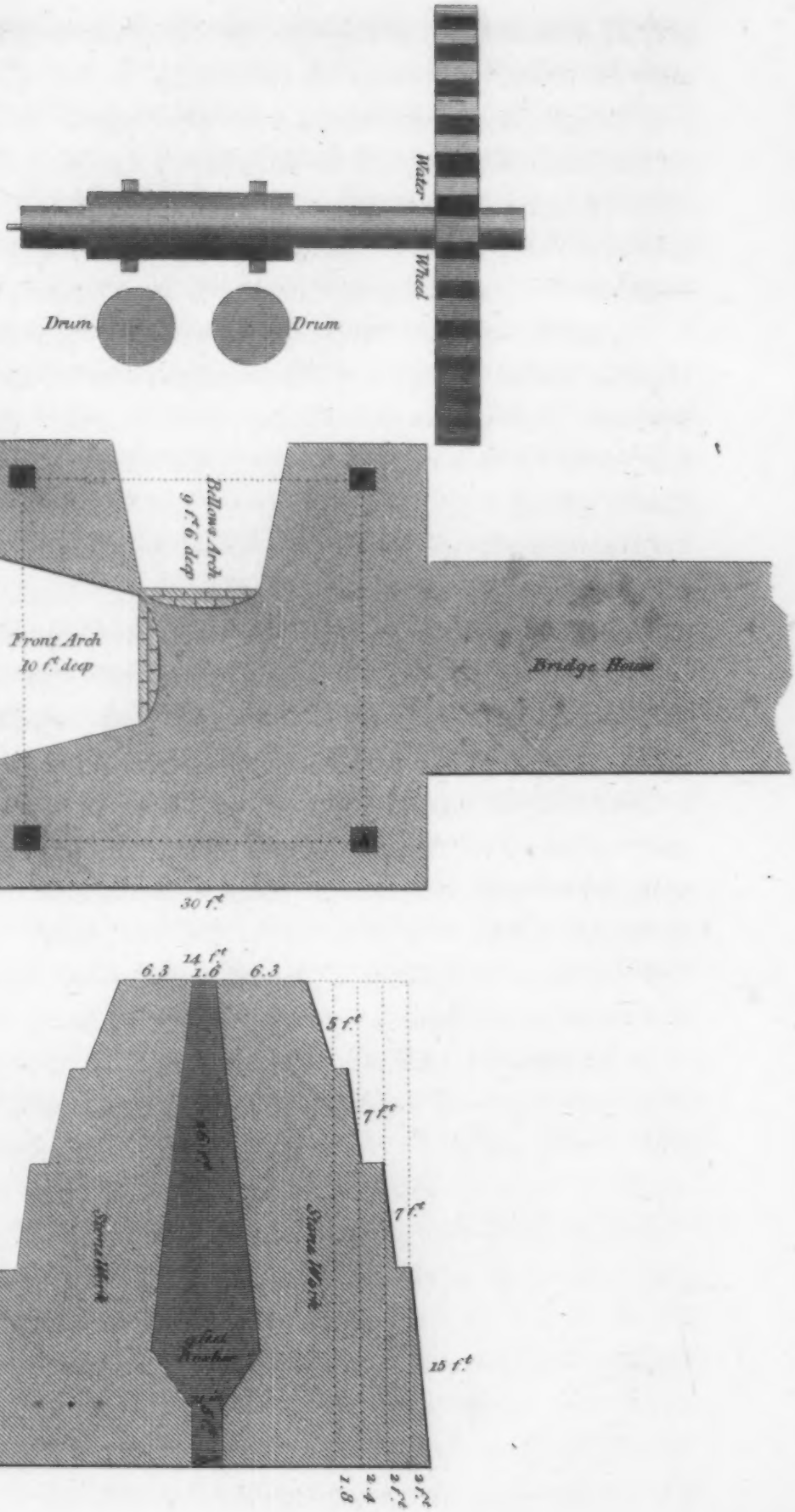
Width of the wheel in the clear 26 inches.

Shrouding 3 1-4 inches by 8 inches.

	Feet.	*In.*
The height from the hearth to the trundle head	31	8
———— from the foundation to the hearth,	5	4
———— from the narrowest part of the boshes to the widest part,	4	3
———— of the tweer (tuyere) from the bottom of the hearth		12
Distance from the nose of the tweer to the opposite wall*	1	6

* The blast of late years is not thrown in quite horizontally, but a little inclining upwards; no doubt an improvement. T. C.

A Modern Pennsylvania Iron Furnace.



W. Strickland del.

C. Tiebout sc.

	Feet.	*In.*
Diameter of the nose of the tweer 3 in. by 2 1-2 in.		
——————— drums	6	
Depth of the drums	5	
Strokes in a minute 4 1-2.		
Hearth from the bottom to the boshes	4	8

Dam stone siliceous grit, calculated to last about six months.

45 cwt. of ore to a ton of metal.

Charge of ore 320lb.
coal 15 bushels, each from 14 to 15lb.
limestone 40lb.

Charges run every 24 hours: 27 to 28.

Wages of carters, banksmen, ore diggers, 61 1-2 cents per day.

——— Fillers 76 cents: ore pounders 69 cents: gutterman 53 1-2 cents: blacksmith 92 cts.

——— Founder 100 cents per ton for pig metal and 266 1-3 cents per ton for hollow ware.

Charcoal 200 bushels to a ton of metal.

In erecting a blast furnace, either sand-stone that will bear the fire, or fire brick should be employed. Sand-stone newly dug out of the ground will be found to contain near ten per cent. of moisture imbibed. If therefore a furnace should require 1000 ton of stone, 100 ton of vapour will require to be dissipated. This can be ascertained by exposing a pound of your stone, to a red heat for two hours, weighing it before and after.

The vents or flues to let out the steam may be repeated every 4 or 5 feet high, and filled with irregular loose stone; they may be 6 inches diameter.

The nose of the tuyere, ought to be kept well plaistered with refractory clay, else the iron is very much disposed to burn.

Of the blast, and the mode of applying it. In al-

most every trial in England, the produce of the furnace has been encreased by encreasing the quantity of air in modern furnaces, beyond the common blast of the furnaces formerly erected. I believe the newly built furnaces of England, have two bellows-arches opposite to each other, and two air pipes. This not only encreases the quantity of air admitted, but in a considerable degree preserves the nose of the tuyere from burning, and the pipe need not project so far into the furnace; nor is it found that the opposite currents of air obstruct each other. This encrease of the volume of air in modern works, *may*, for aught I know, be more advantageous in the pit-coal furnaces, than in the wood-charcoal furnaces; but I am strongly inclined to think that there is great room for improvement in this respect, even among our charcoal furnaces of Pennsylvania. The following remarks of Mr. Roebuck, one of the owners and managers of the Devon iron works, are considered as having been confirmed by all late experience. 6 Ph. Mag. 331.

"This improper measure, however, afforded me the opportunity of immediately putting in practice the plan I have mentioned.

When one of the furnaces was stopped, the other continued to be blown by a blow-pipe of two and three fourth inches diameter, and the produce of the furnace, for several weeks thereafter, was not 20 tons of iron *per* week at an average. The engine at this time was making about 16 strokes a minute, with a stroke of the air-pump, about 4 feet 8 inches long; but when I altered the diameter of the blow-pipe, first to 3, and immediately after to three and one-fourth inches diameter, and regulated the working gears of the engine, so as to make a stroke of five feet two inches long, and about 19 strokes in a minute, on an average, the produce was immediately increased. It continued to be, on an average of nine months

immediately after this improvement, at the rate of 33 tons of iron *per* week, of as good quality as formerly; for during this period, from the 21st of November, 1795, to July 30, 1796, this one furnace yielded 1188 tons of iron. No more coals were consumed in working the blast-engine, or other expences about the blowing machine incurred, and therefore no more power was employed to produce this great effect. It is also of much importance to remark, that the consumption of materials, from which this large produce was obtained, was by no means so great as formerly. The furnace required very considerably *less fuel, less iron-stone, and less limestone*, than were employed to produce the same quantity of iron by the former method of blowing; and according to the statements made out by the company's orders, as great a change was effected in the economical part of the business.

From the success of this experiment, so well authenticated, and continued for several months, I am led to be of opinion, that all blast furnaces, by a proper adjustment of such machinery as they are provided with, might greatly and advantageously increase their produce, by assuming this as a principle, *viz.* "*That with the given power it is rather by a great quantity of air thrown into the furnace, with a moderate velocity, than by a less quantity thrown in with a greater velocity, that the greatest benefit is derived, in the smelting of iron-stones, in order to produce pig-iron.*" However, it is by experiment alone, perhaps, that we can be enabled to find out the exact relations of power, velocity, and quantity of air requisite to produce a *maximum* of effect."

Formerly in England as in this country, when charcoal was used, many of the furnaces were mere bloomeries, worked by hand-bellows, or a small water-power. Then were introduced wooden drums, strongly hooped, with safety valves or snorts, still very common in America, and

worked by a water wheel. To these succeeded as a great improvement in England, cast iron cylinders, in which a piston is worked by the power of a steam engine, (for in that country, iron works are very commonly put into operation by the power of steam) of late (that is within these 15 years) the mode generally pursued of equalizing the blast, is, by means of a column of water. Large iron chests are inverted in water, and the water between the outside containing-vessel, and the inside inverted-vessel, into which the air is thrown, serves to give by the re-action of its weight an equal pressure to the air thus thrown in, and which is again conveyed from the inverted chest into the tuyere. On this subject, I give the following essay from 6 Phil. Mag. 60, 113.

"When it is considered that in the smelting operation the reduction of immense quantities of materials is effected by a compressed current of air impelled by the whole power of a blowing machine, the consequences of the change of air, either in quantity or quality, must be very obvious: when, farther, we contemplate the metal called into existence by means of combustion thus excited; when we consider iron as having the most powerful affinity for the base of that part of the air which maintains combustion; and when we view the debased state to which the metal is reduced by coming into improper contact with it, we must conclude, that the application of blast in the manufacturing of iron, calls for the most minute and thorough investigation. In order to take a comprehensive view of this subject, the following division will be requisite:—

1st, The intimate connection which the quantity of blast bears to the area of the internal cavity of the furnace, and to the nature of the pit-coal.

2d, The various modes by which air is procured, and how these respectively affect the quality of the air.

3d, The various changes to which air is subjected by a change of temperature in the atmosphere, with the consequent effects.

4th, How far increased or diminished velocity and compression alter the results of the furnace.

5th, The form and diameter of the discharging-pipe.

1st, Then, in the construction of a blast-furnace and blowing-machine, the quantity of air to be used ought to depend upon the internal dimensions of the former; which, again, ought to be formed according to the quality of the pit-coal. Upon the softness or hardness of the coal, ought more immediately to depend the height of the blast-furnace. This necessary precaution has given rise to a vast variety of furnaces, of different capacities, from 30 to 50 feet in height, and from 9 to 16 feet diameter at the boshes. Furnaces from 30 to 36 feet are used for the softer qualities of coal, such as a mixture of free-coal and splint. Furnaces from 36 to 45 are appropriated to the burning of splint-coal coaks; and in Wales, such is the superior strength and quality of the pit-coal, that the furnaces admit of being reared to the height of 50 feet.

These various qualities of coal, it has been formerly shewn, have appropriate weights of iron-stone, and, to use the language of the manufactory, are capable "of supporting a greater or lesser burden of mine." The former qualities admit not of having the air discharged in great quantity, unless it is impelled under an uncommon degree of compression and consequent velocity incompatible with the operations of a steam-engine. The reason is obvious: when air, loosely compressed, or comparatively so, is thrown into a body of ignited fuel, the mechanical structure and continuity of whose particles are soft, the air is much more easily decomposed; the ignition, of course, is more rapid: the descent of the materials is promoted beyond their proper ratio, and long before the carbona-

ceous matter has penetrated the ore, or united to the metal, to constitute fusibility. I shall adduce an example, as being most illustrative of this doctrine.

Suppose a blast-furnace, 35 feet high, 11 feet wide at the boshes, properly burdened, and producing No. 1, pig-iron. Let the discharge of air be supposed equal to a pressure two and a half pounds upon the square inch, or equivalent to 1-6th of the atmosphere, or 5 inches of mercury: under these circumstances let it farther be supposed, that 1500 cubical feet of air are discharged in one minute; and that the diameter of the discharging-pipe is 2·625, the area of which is equal to 6·890625 circular inches. Let the discharging-pipe be increased to 3 inches diameter, and let the same quantity of air be passed into the furnace; it is evident that as the area of the discharging-pipe is increased to 9 circular inches, or nearly 1-3d more than formerly, the compression of air must be proportionally diminished. This alteration is soon perceived by its effects; the quantity of scoria increases from the furnace, whilst the consumption of the materials above is also considerably augmented. In a few hours the scoria will have undergone a complete change, from pure white, enamelled with various blue shades, to a green, brown, or black colour, considerably charged with the oxyd of iron*. The same effects will continue, in greater or lesser degree, till all the materials are reduced which were existing in the furnace at the period of diminished compression. The philosophy of this fact may be accounted for in the following manner:—

While the just association of proportions remained, the air was discharged under such a degree of compression as to excite proper combustion: the decomposition of the air by means of the ignited fuel, was not effected in imme-

* The metal will have lost nearly all its carbon, and have become inferior in value 25 to 30 *per cent.*

diate contact with the separating metal, but had, by its uncommon degree of density, resisted decomposition in the ignited passage, and had been decomposed upon the coaks at a greater elevation in the furnace. As a proof of this, we frequently see a tube formed throughout the breadth of the furnace, quite black and apparently cold, formed of the fused materials: when this is removed, a considerable descent momently takes place of coaks heated visibly beyond the common pitch: these inflame rapidly, but are soon again cooled to blackness by the incessant discharge of air upon them. The descending mixture of iron and lava are in like manner cooled around the line of blast; the tube is again formed, and, if not removed, will remain for days together, while the furnace will be otherways working in the best manner.

When by accident or design the compression and velocity of the blast are diminished, the tube begins to burn, and throws off a great many red fiery-coloured sparks, the sides and roof fail, and are carried before the blast in all directions. Sometimes considerable cloats of imperfect iron are recoiled with such violence as to escape the vortex of blast, and issue from the tuyere-hole with such velocity as to inflame in the air, and fall down in the state of oxyd. In the end the tuyere will appear to flame and all the passage inwards shews an astonishing degree of whiteness. The decomposition of the air is instantaneously effected upon its entering the ignited passage; the iron by this means is exposed to the oxygen that is disengaged; and the vast quantity of caloric set free, in consequence of its union with the iron and carbon, produces the astonishing heat now visible, but which formerly took place at a more proper height in the furnace.

From this it will appear, that although a greater apparent degree of heat is visibly produced by the sudden decomposition of the air, and a more rapid descent of materials

for some time is the consequence, yet, as the quality of the iron is impaired, and as in the end the furnace will return to its old consumption of materials as to quantity, the effects of a loose soft blast are conclusively pernicious.

It sometimes happens, that when a loose blast is surcharged with a considerable portion of moisture, or comes in contact with coaks which had been wet when introduced into the furnace, the inflammation which takes place at the tuyere is prodigious: fine fire-clay will be melted down and blown to slag in a few minutes; the sides of the furnace, composed of very infusible fire-stone, is next attacked, and in a few hours will be so completely destroyed as to stop the working, and require immediate repair. Effects similar to those now described will be felt when blast is improperly proportioned to coal of a stronger continuity of fracture and superior quality. Besides the effects produced by the sudden decomposition of iron, others of like nature are produced where a soft coal is used, a small furnace and a great discharge of blast.

It has been found that crude iron, to be properly matured, ought to remain in the blast furnace, according to circumsances, 48 to 60 hours; that is, from the period that the iron-stone is introduced till such time as the metal begins to occupy its place in the hearth in a state of perfect separation. When the contrary is the case, the mixtures arrive at the hottest parts of the furnace before the metal has taken up a sufficient quantity of carbon from the fuel; the action of the blast, and the immediate heat by which the ore is surrounded, forces the iron from its connections to the bottom of the furnace. The quality is de-carbonated, and reduced in its value: to restore this again, the local portion of fuel is increased; this adds to the expence of manufacturing, and diminishes, in some measure, the smelting of the furnace.

When splint-coal coaks are used in the blast-furnace, the blast admits of being thrown in under the highest possible pitch of compression; the uncommon density of the charcoal sustains a very powerful discharge of blast before it is dissipated to facilitate the general descent. Most frequently, large masses of these cinders pass through the whole ignited cavity, and are thrown out below, possessing all the acuteness of their original form and fracture.

This quality of coal is used in all the Curson blast-furnaces, where, to ensure a respectable produce, the air is discharged under a pressure equal to 3 1-4 pounds upon the square inch, or 6 1-2 inches of mercury.

The same quality of coal was used at the Devon iron-works, where, at one time, having all the blast of a 48 inch cylinder engine thrown into one furnace, the column of mercury supported was upwards of 7 inches; the quantity of air discharged under such an impelling power, I found to exceed 2600 cubical feet *per* minute.

The coals used at the Cleugh, Cleland, and Clyde iron-works, are nearly of the same quality at each—a mixture of splint and soft coal. The Muirkirk and Glenbuck iron-works have a coal different from any of the former, and in some particular spots it considerably resembles the English clod-coal.

2d, The various methods of procuring air for the blast-furnace may be reduced to the following:—1st, That procured by cylinders, and discharged into the furnace by means of a floating piston heavily loaded, and working in a large receiver or regulating cylinder: 2d, That wherein pumping cylinders only are used, and the air thrown into chests inverted in water, called the *water-vault:* 3d, That mode wherein the air is discharged from the pumping or forcing cylinder into an air-tight house, called *the air-vault.*

The first method is the original mode of blowing, and is still much used at those iron-works whose erection has

been prior to the last fifteen years. By this mode the quality of the air is less subject to alteration by a change of atmosphere. The principal objection to this manner of blowing, is the want of capacity in the receiving cylinder; which cannot be increased so much as to take away the considerable intervals which occur at different parts of the engine-stroke. This effect is sensibly seen by the speedy and irregular ascent and descent of the column of mercury. In water blowing-machines, where the air is raised by three or four cylinders worked by means of a crank, where the air is received into an air-chest, and forced into the furnace by the continual action of the blast of each successive cylinder, the current of air is steady, and supports the column of mercury with great uniformity.

The use of the water-vault has of late years become very general among new erected works. Its properties are, a steady and very cold blast: the largeness of the receiving cisterns gives them a sufficient capacity to retain every pound of air raised by the furnace, and distribute it to the greatest advantage. This is not the case with the floating pistons, where a certain quantity of spare wind is thrown out at every return of the engine, lest the great piston and weight should be blown out of the cylinder altogether; which, indeed, sometimes happens. The only objection which remains in force against the use of the water-vault, is the tendency which it has to take up a considerable portion of the water in solution, and introducing it into the furnace. A judicious arrangement of the conducting-pipes would in some measure obviate this, as well as the more dangerous tendency which water has to rise in a pipe speedily emptied of its air by the stopping of the engine: a stream of water thus conveyed to the furnace, would be productive of the most awful consequences.

The air afforded by the air-vault is much inferior to that obtained in the former methods. This immense ma-

gazine of compressed air generates a considerable portion of heat, which greedily seizes the damps, which are unavoidable in underground excavations, and conveys them to the furnace. The blast is, however, steady and uniform; and when the inside of the building is completely secured against the passage of air, it is productive of considerable effects in the furnace. In the summer months, however, the air becomes so far debased as to affect the quality of the iron, and change it from grey to white. Every change in the temperature of the atmosphere during this period, is indicated by various changes in the furnace.

The largest air-vault hitherto in use was excavated out of solid rock at the Devon iron works: the fissures of the rock admitted considerable quantities of water; and the same degree of damp would always prevent the possibility of making the side-walls and roof air-tight by means of pitch and paper, &c.

Besides the various natures of blast, as to the strength and equality of the current afforded by different modes of constructing the blowing-machines, a variety in the quality of the air obtained is also an invariable consequence: this is sufficiently known by the effects which it produces in the blast-furnace, and ought to be subject to scrupulous examination.

In this, as in other countries, larger products of cast iron are obtained in the winter months than during the summer and autumn seasons: the quality of the metal is also much more carbonated, and with a less proportion of fuel. In many parts of Sweden, where the summer heats are intense, the manufacturer is obliged to blow out or stop his furnace for two or three months: not only is he unable to make carbonated metal, but is frequently incapable of keeping the furnace in such trim as to make a produce of any quality whatever. In Britain, during the months of June, July, and August, more especially in dry seasons,

the quality of the iron, with the local proportion of fuel, will be depreciated 30 *per cent.* and the quantity reduced to 2-3ds or 3-4ths.

In seeking for a solution of this universally acknowledged fact, our attention is naturally directed to an examination of the various states of air. The quality of the air in winter is more fit for combustion than in summer, is a truth which requires no farther demonstration. Greater coolness, whereby an almost complete refrigeration of moisture takes place, and the presence of perhaps a greater relative proportion of oxygen, may account for this phenomenon. On the contrary, the quality of air during the summer months becomes much contaminated for combustion, by holding in solution a much greater quantity of moisture: the abundance of nitrous particles may also diminish the usual proportion of oxygen.

This will account for the inferior effects of combustion both in common fires and in the blast-furnace; it will also in a great measure tend to solve the curious phenomenon of pig-iron taking up less carbon in summer, although reduced with a superior quantity of fuel. The air discharged most probably contains less oxygen; yet the metal is much less carbonated than at other times, when contrary proportions of these exist. Most probably the deficient carbon is carried off by dissolving in hydrogen, forming a constant stream of hydro-carbonic gas, while the oxygen that is set free unites to the iron; and while it reduces its quality, at the same time the quantity is reduced by a proportion of the metal being lost in the scoria*.

* May not the superabundant azote of the summer atmosphere produce part of these effects, by dissolving a portion of the carbon, and forming carbonated azotic gas, as has been proved by M. Lavoisier? Mushet.

There is no superabundant azot in a summer atmosphere, nor any nitrous particles. T. C.

To correct these occasional imperfections in the quality of the air, and to devise methods to procure air always fit for proper combustion, ought to be an object of much consideration to the manufacturer of cast iron. Whether such a consideration has given rise to the different modes of receiving and discharging the air now in use, I cannot say; I rather think not: a great quantity of air has hitherto been a greater object than a certain and uniform quality; and in a country where there is more temperate and cold weather than hot, it is by far the most important object: to unite both, however, would be an attainment of the greatest utility, and would rank the discoverer amongst the well-deserving of his country. How far the mechanism of our present machinery has been adapted to the exigencies of our atmosphere, will appear upon examining the nature and properties of the air, judged by its effects upon the blast-furnace.

The air produced by the blowing and receiving-cylinder is less changed, and less subject to change, than that produced and lodged in contact with a vast body of air or water. If the blowing-cylinder is fixed in a dry cool spot, the only difference which the air undergoes is an increase of temperature; this is so very considerable, that upon entering the blowing-cylinder immediately after stopping the engine, I have found the thermometer rise fifteen to seventeen and a half degrees higher than the surrounding air. That this heat is generated in the cylinder is unquestionable; but whether it is occasioned by the friction of the piston leather upon the sides of the cylinder, or expressed from the air by its severe compression, I have not yet been able to decide. It very probably arises from both causes, although the latter is sufficient to produce a much greater degree of heat. What effect this increase of temperature has upon combustion we are unable to say, as the degree of heat accumulated will at all times bear a

reference to the temperature of the surrounding air, and as there is no method likely to be devised where heat would not be generated by the action of the particles of air upon each other. When the bulb of a thermometer is held in the middle of the current of blast, as it issues from the discharging-pipe, a temperature is indicated as much lower than the temperature of the surrounding air, as the temperature of the cylinder was higher; and it is most probable that a much lower degree would be obtained, were it not for the previous expression of some heat in the blowing-cylinder. Upon the whole, I think, the quality of the air obtained in this way of blowing uniformly, most fit for combustion, provided the numerous pauses and irregularities of the current of air were done away.

Air forced into the furnace under water pressure always contains a considerable portion of moistrue; the blast of course is colder, as it issues from the discharging-pipe. The temperature differs so much from that of the external air as to sink the thermometer from 54° down to 28° and 30°. Such effects are produced by air coming into contact with water, that, although the temperature of the atmosphere is 60, 65, to 70, yet the blast at the orifice seldom rises above 38: the cold produced in this manner is much increased if the air is surcharged with so much water as to be visible in the state of a fine spray. The leading feature, therefore, of the water-vault, as to its effects upon the quality of the air, seems to indicate an almost uniform degree of temperature in the blast: this can only be occasioned by the warm air in summer taking up a greater portion of the water in solution, the escape of which at a small orifice, and under a great degree of compression, produces the very great depression of the thermometer. I have already hinted at the bad effects produced by moist blasts, and shall, in a proper place, more minutely atttend to them.

The most inferior quality of air used in the blast-furnace is that thrown into the air-vault, and afterwards expressed from thence by its own elasticity and the successive strokes of the engine. The capacity of such a building is from 60 to 70,000 cubical feet; this, when filled, generates a much superior degree of heat to that sensible in the blowing-cylinder. As this heat is produced many feet distant from any mechanical motion, it is most evident that it is extricated from the air, and will readily unite with the moisture which penetrates the building: the quality of the air introduced into the furnace will therefore be in proportion to the quantity of moisture taken up; this will be much more in summer than in winter, as the temperature of the former exceeds that of the latter. The sensation, on entering the air-vault in the coldest months, immediately after stopping the engine, is exactly similar to that experienced upon entering a crowded room in the hottest summer day; the walls are covered with damp, and the superior regions of the vault readily obscure the flame of a candle. The feeling, upon remaining in the air-vault when the engine is at work, is less marked than would be expected where so great a compression of air existed; the sense of hearing, owing to the moisture in the conducting medium, is considerably impaired, and respiration is performed with some difficulty; the light of a candle is faint, and not visible at the distance of a few feet.

I have explained the necessity of just proportions existing betwixt the area of the interior of the blast-furnace, the quantity of air thrown in *per* minute, and the quality of coal. The various modes of blowing, and their respective effects, deduced from strict observation, were also attended to. We have now, 3d, to adduce examples where the various changes of the atmosphere, as to heat and pressure, occasion the most sensible difference in the

quantity of materials consumed, and in the quality and quantity of metal produced.

It has been already demonstrated, that the air in winter, by containing less moisture, is more proper for combustion, and more calculated to produce carbonated crude iron, than the air existing at any other season. From this superior quality the manufacturer obtains advantages, which induce him to wish for a continuance of cool air throughout the whole year. These effects are not, however, uniform; they depend greatly upon a light or heavy atmosphere. The keener and more still the air, the more rapid the combustion. During a severe frost, the descent of the materials is facilitated from one tenth to one fifteenth more than in rainy or hazy weather, and at the same time the quality of the iron is rather improved than impaired. When a change from frost to snow or rain takes place, the effects frequently become almost immediately obvious: the colour of the flame at the furnace head is changed; the tuyere of the furnace inflames, and burns with great violence; the lava, as it flows from the notch of the dam-stone, becomes lengthened and tenacious; the form of it is changed, and the colour undergoes the most visible alterations; the iron no longer retains its complete saturation of carbon, but flows out sensibly impaired of its fluidity, and, when cold, the privation of carbon is most evident by the examination of its fracture.

When such consequences arise from the transition so frequent in winter from frost to thaw, it will be easily conceived that the change effected during the milder and warmer months must produce proportionally additional effects. The increase of temperature by taking up, and holding in solution, a much greater portion of aqueous vapour, will account for the ordinary effects which are annually observable in every work. Where these pernicious

consequences approach to extremity, a solution of the phenomenon will likely be obtained by the examination of the blowing-apparatus. If air is fitted for combustion in proportion as it is free from watery solutions, we are not to expect similar results from these blast-furnaces in summer, which are blown by air from the regulating cylinder, and those blown by air from a water or air-vault. I have for years seen this fact verified, and superior quantity and quality of iron during the hot weather, obtained from a furnace excited by means of blast, from the simple regulating cylinder, with a less proportion of fuel than from furnaces whose air was expressed by means of the water or air-vault. Observations thus made, where every day the effects of the different means could be justly estimated and compared, have led me to the following conclusion: That the quality of the air, as furnished us by nature in our atmosphere, is uniformly more fit for the manufacture of crude iron to profitable account, when discharged simply by means of cylinders and pistons, than when brought into contact with moisture either in the water-vault or air-vault.

So imperfect has the quality of the summer air been found in this country for combustion, where the water-vault was used, that experiments have been made to repair the deficiency of effect by introducing steam into the furnace by means of an aperture above the tuyere. The inducing motive to this act, was a belief, that combustion was diminished in consequence of a diminution of oxygen gas during the summer; that, by introducing water upon a surface of materials ignited to whiteness, decomposition would ensue, a larger quantity of oxygen would then be presented to the fuel, and superior effects, as to combustion, obtained in this manner than hitherto witnessed. The idea was ingenious, and, in its application to the manufacture of cast iron, original; but the

whole train of facts, laid down in this and former papers, as to the effects of a superabundant quantity of oxygen, was overlooked. The event proved in the most complete manner, and on a great scale, the pernicious effects of moisture. The furnace gradually became cooled where the steam entered; the heat, set free by the decomposition of the water and the disengagement of oxygen, increased to an alarming pitch a considerable way up the furnace; the quality of the iron became brittle, and as white in the fracture as silver; the introduction of the steam was still continued, the descending materials were instantly robbed of their heat to facilitate the decomposition of the water, and by-and-by the furnace closed entirely over, and the experiment ceased.

This experiment, performed in a furnace 18 feet high, is a complete proof that heat is disengaged from bodies while they pass from the fluid to the aeriform state. The first instant of the discharge of steam, a very considerable portion of heat would be withdrawn from the fusing materials and united to the water. This, in its turn, would be ignited to whiteness, and decomposed upon the metals and coaks, in a superior region of the furnace. The process continuing for several hours, the materials at the tuyere were at last so completely deprived of the caloric by the continual torrent of steam, that they lost fluidity, cooled rapidly, and at last became black. Had another aperture for steam and for air been opened above these, now entirely shut up by the consolidated materials, the same effects would have been produced; the immense quantity of caloric, disengaged by the decomposition of the ignited water, would now approach nearear to the top of the furnace, another stratum of fusing materials would again become consolidated, till in the end the whole furnace would be set fast from top to bottom. From the introduction of steam into the blast furnace, either as

such, or under a superior degree of expansive force, the following important truths may be learned: That the quantity of oxygen which enters into our atmospheric compound is generally more fit for the manufacture of the superior qualities of crude iron than any mixture which may be furnished by the addition of water: that, although the decomposition of water, by furnishing a superior quantity of oxygen, and by throwing off a relative proportion of caloric, increases the effects of combustion immediately in the vicinity of this chemical analysis; yet, as the water had previously abstracted the heat necessary to its decomposition from the inferior strata, a greater quantity by no means exists in the furnace. The water, in fact, only serves as a medium to convey the heat from one particular spot, but, by attempting to fly off with it, meets decomposition, and renders up not only the abstracted heat, but that which was contained in the oxygen of its decomposition*.

4th, The compression and velocity of the air discharged into the furnace, considerably affect the results of the smelting operations. In the consideration of this subject the various qualities of coals will be found to have an intimate connection with the area of the discharging-pipe and the compression of the blast. It has already been more than once observed, that a soft or mixed quality of coal is more susceptible of combustion than either the splint or clod-coal: the consequence of this is, that, unless the necessary compression of air is used, decomposition is too early accomplished, and the coaks become oxygenated by combustion in a greater ratio than is proper for the carbonation of the metal. To avoid this the column of air ought to be discharged, in the case of soft

* The introduction of vapour or steam is not well understood. I have seen steel made by introducing steam to melted iron; but I do not understand the way in which it operates. T. C.

coals being unavoidably used, under such a degreee of compression, as to resist entire decomposition in the ignited passage. In that case, the iron does not so immediately come into contact with oxygen, as the decomposition is chiefly effected in the superior strata of the separating materials. Under the former circumstance, of a loose unconnected stream of air being thrown upon coaks easily combustible, the quality of the metal, with the same quantity of fuel, becomes oxygenated, the tuyere becomes fiery, and frequently emits sparks of metallic oxyd. The separating iron may be viewed as it oozes from the ore in small gobular masses, frequently on fire, changing its state to that of an oxyd. The combination of oxygen, by altering its density, makes it subject to the re-action of the blast, which at times gives it a direction from the tuyere with considerable violence. Those parts of the iron (by far the greatest) thus oxydated, which escape not at the tuyere, mix along with the fused earths of the ores and limestone, alter their colour, and flow from the furnace more unrevived than at their first introduction. It is, however, very different, even with this inferior quality of coal, where the density of the blast is proportioned to the inflammability of the fuel. Qualities and quantities of crude iron may be produced from this, equal to those from coals reckoned of a superior nature. The metal becomes as highly saturated with carbonic principle as that made from clod or splint coal. The tuyere evinces that decomposition is effected in its proper place. The fluid masses of iron, as they become expressed from the ore, are shivered into spray, before the dense column of air, without exhibiting the least symptom of decomposition. They again unite under the level of the blast, increase in size, and sink through the fluid stratum of earths to the bottom of the furnace. This fact holds out one of the strongest proofs of the great affinity which carbon and

iron mutually possess towards each other. In the case of the iron separating in an oxygenated state destitute of carbon, it immediately falls a prey to its affinity for oxygen. In the latter case, the iron, being completely carbonated, resists decomposition by the sacrifice of a very small portion of its carbon; it further proves, that the affinity of oxygen is greater to carbon than to iron; and that, before iron becomes oxydated, all the carbon is taken up.

The continuity of the particles of splint coals renders the coaks of difficult combustion, capable of withstanding a most powerful discharge of air, in quantity and in the degree of compression, without entailing effects similar to those produced with the use of softer coals: this renders the operations with splint coal less subject to casualty and to change. Carbonated iron with a proper blast is more uniformly obtained, and frequently a very superior quantity. Similar effects are produced with the clod coal, but in a more eminent degree. Discharging-pipes are used four inches in the diameter, and the compression only equal to two pounds on the square inch; yet the same fatal effects are not known as in the use of soft coal, which, with such a column of air, would require the pressure to be equal to 3 1-2 upon the square inch at least.

5th, Upon the form and construction of the discharging-pipe, effects of more considerable importance depend than is either generally allowed or even conceived. At some iron-works, no peculiar shape is adopted: if the tube is sufficient to convey the air, and the mouth of it nearly of the size wanted, the interior construction is entirely overlooked. This indifference, however, is by no means general: variously constructed pipes are used at different works, and at some places it is preferred to throw in the air *from two pipes* whose areas are only equal to one of the usual size.

The various shapes may, in point of the principle of their construction, be reduced to three. (See Plate, Fig. 1, 2, 3.)

To understand properly the objectionable parts of the construction of nose-pipes, it must be recollected, that much has been said to depend upon the blast reaching the opposite extremity of the furnace, as little impaired of the compactness and velocity of its original discharge as possible. When it is otherwise, the results in the internal operations of the furnace must be consequently altered. If the compression is diminished 1-2 or 2-3ds when it reaches the opposite wall, decomposition in that portion must be effected before the air has attained its elevated situation in the furnace. It is even possible to disperse the whole column of air in such a manner that the ignited materials of the opposite side may receive little of its effects to promote combustion.

The discharging-pipe Fig. 1. is frequently used: its length is 12 inches or more; the discharging aperture 3 inches, the other end 5 inches; but this is arbitrary, depending upon the size of the adjoining pipe. From a pipe thus constructed, the air disperses or diverges too suddenly; and at a small distance from the orifice, a considerable portion of it answers but imperfectly the purposes of combustion. Part of it is speedily decomposed and the oxygen brought into immediate contact with the iron. The quantity of metal is reduced by the former, and the quality injured by the latter. Though long custom, by a continued use of such shaped pipes, has prevented their pernicious effects from being observed, yet they must prove, in many cases, detrimental to the œconomical distribution of air, and the manufacture of iron.

Fig. 2. represents a nose-pipe, of another construction, even more exceptionable; because the air dispersing still

more suddenly, in a degree somewhat proportionate to the more sudden contraction of the pipe, a considerable quantity never enters the furnace, but, striking on the exterior wall, is thence repelled.

A discharging-pipe constructed as in Fig. 3. would obviate, in a great measure, the imperfections of the two former: the length of the tapered piece is 12 inches, of the straight pipe, 6 inches; extreme diameter as in the others, 5 inches; diameter of straight pipe, 3 inches. From such a pipe it is conceived that the blast will proceed to the greatest possible distance unimpaired in compression and velocity. So far, therefore, as the absolute force of the blast and breadth of the furnace will permit, decomposition will be prevented on the level of the pipe, and the manufacturer freed from the evils which I have above detailed, as attendant upon decomposition in that quarter." (Mushet.)

For drawings of the ground plan, sections and elevations of a water-blast I refer to Mr. Mushet's paper, 6 Phil. Mag. 362, to Roebuck's paper in the same volume p. 324, copied into Rees's Encyclop. articles Blast and Blow.

Let it then be remembered, that among the points suggested thus far as to the smelting of iron, are the following.

1st, That as the principal object is to procure metallic iron out of the ore, the first step is to get rid of all stony heterogeneous matters, by sorting the ore when necessary, by roasting, by washing.

2dly, That the pieces of ore prepared for the furnace, should not much vary, or much exceed the size of an egg.

3dly, That roasting, in contact with charcoal dust, has the following effects: it drives off sulphureous and arsenical particles, if there be any: it drives off superfluous moisture; it drives off carbonic acid gas by causing the oxygen of the ore to unite partially with the charcoal, and

form that gas; the ore thus approaches still nearer to a metallic nature, becomes magnetic, and requires less charcoal in the furnace to make it into metal. But if the charcoal dust be in too small a quantity, or the roasting continued with access of air too long, or if the red hot iron-stone be exposed without coal dust to a current of air, the ore does not lose, but gains in weight by attracting the oxygen of the atmosphere; it becomes more refractory and infusible, and requires more fuel to metallize it: the difference between a piece of iron ore, and a piece of iron, being for the most part, that the first is, and the second is not, combined with oxygen, carbonic acid or sulphur.

Perhaps the roasting is better done in ovens: Jars in 2 Voy. Mineralogiques planches 1 and 9, has given the oven employed for roasting ores of iron in Styria and Carinthia, and the coak oven of England: the only question here, is, would the convenience pay the expence.

4thly, If the washing be not skilfully performed, there is great hazard of washing away the ochry or metalliferous part of the iron-stone as I think I have seen.

5thly, That it is worth while to ascertain whether the iron ore is accompanied by earths or stones of the clay class, or the limestone class, or of the sand-stone or flinty class, in order that limestone as a flux, may not be indiscriminately used in the same proportion to all kind of ores. The less earth of any kind is mixed with the ore, the less limestone is needed.

6thly, Limestone being the flux that brings all other earths into fusion, a mixture of limestone ore with clay ore, or sand-stone or flint ore, promotes their fusion. Hence, limestone is to be added to clay ore and siliceous ore, but it would be useless and superfluous to add it to a limestone ore. In this case, another kind of ore should be brought to and mixed with the limestone ore. In England, the slag of previous fusions is much used.

7thly, That much trouble and expence may be saved by thus mixing ores of different qualities. So too, the rich primary iron ores, that are not enveloped in earth, may be frequently mixed with good effect with the secondary ores, where the distance will allow the expence of carriage. By the primary ores, meaning such as are found in or near the strata called primitive by the mineralogists, such as hematitic iron ore, heavy compact red iron-stone and similar ores, which may be mixed with the common earthy iron-stones to good effect especially in charcoal furnaces. This is done in England where the Lancashire and Cumberland ores are so mixed with the poorer iron-stones in the coak furnaces.

8thly, That the limestone earth to become a flux, should be added in proportion as much at least as the predominant earth of the ore to which it is applied. Thus, if the iron be enveloped when put in the furnace in clay and sand-stone of which the clay is about 2 parts and the sand-stone one, the limestone should be 2 parts also, or equal to the clay: this rule applies, not to the whole weight of the iron stone, but merely to the earths mingled with it.

9thly, The more moisture your ore, and your charcoal contains, the more fuel and air, you must use to get rid of it: and also,

10thly, The more moisture your ore and your charcoal contains, the more fuel is carried off in forming steam, and is wasted in combining with the oxygen that is formed by the decomposition of the water, which contains by weight 85 parts of oxygen in 100.

10thly, If your charcoal be not well burnt, it employs the contiguous charcoal in the furnace to burn it; wherein there is waste.

11thly, The use of the charcoal or coak, (the fuel) is threefold. It is employed to give heat and bring every thing into liquid fusion: and it is employed to supply carbon to decompose the ore, and abstract from it its oxy-

gen, which prevents its becoming a perfect metal: and it is employed in adding a further dose of carbon to the pure iron, which thereby becomes much more fusible. The carbon in crude iron supercarbonated, is in a great degree mechanically mixed with the iron as the surface of highly carburetted kishy iron, shews: in steel, the carbon is chemically united to the iron. Good fresh charcoal may be considered as containing seven eighths of carbon.

12thly, The limestone is in proper proportion, if the slag is thin and does not retain any particles of metallic iron enveloped in it. Otherwise, the heat has not been sufficient; or the limestone is not in proper proportion; or the charge has descended too soon; or the blast has not been sufficient in quantity, strength, and regularity, to consume the coal; or it may also be in too great proportion for the coal, thereby cooling the metal or the slag in its ascent from the tweer; for the blast that is not employed in producing heat with the charcoal, will produce cold: and still worse, it will re-oxygenate the iron.

The skill of the man who manages the furnace is shewn, in his proportioning his flux to his ore, so that there shall be thin fusion with as small a quantity of coal as possible —in using none but well burnt dry coal, that none may be wasted—in using coal enough and no more to give the required heat and carbonization; for which purpose the air thrown in and the coal thrown in, must consume each other. If the air be in too great proportion, the charge will be cooled: if in too small a proportion the charcoal will not be used up. Wherever great lumps of charcoal are seen floating on the slag or enveloped with it, there is want of skill in adjusting the proportions.

13thly, The charcoal to be entirely consumed without waste, should not be thrown into the furnace in large lumps, for there is not time in this case during its descent, for the air and the iron to decompose it.

14thly, As the charcoal requires time to be decomposed, and the iron ore requires time to be metallized and carbonated, the size and slope of the boshes should be regulated by attentive observation of the process in all its course, during the first period of blast: for ore of one kind may be carbonized quicker than ore of another kind, and therefore may be permitted to descend more speedily (in comparison.) This must be the result of close and local attention.

15thly, I am not qualified to give an opinion, but I would suggest, that in Pennsylvania generally, there has been error, rather in giving too little than too much blast. Also, that a slight inclination of the blast upward rather than an horizontal stream, is to be preferred. For, in the latter case, there is (as I think) danger of cooling the slag, or oxygenating the metal. Also, whether the same quantity of air, would not answer a better purpose from two pipes in opposite directions than from one?

16thly, It appears, that pit-coal or coak furnaces, require to be higher, and require also a greater blast to consume and decompose the fuel than charcoal furnaces; and the ore requires a longer time to be metallized than with wood charcoal: I have sometimes thought the Pennsylvania furnaces are somewhat higher than necessary. I have measured the plates in Jars, and find the dimensions of various furnaces as under.

	Ground plan.	*Width at the boshes.*	*Height from the hearth.*
Iron furnace at Eisenhartz	13	8. 3	33
Treyback, in Carinthia	16	4. –	22
John-Georgen-Stadt, in Saxony	29	5. –	21
Sweden	25 6	7. –	25
Laurwig, in Norway	30	8. –	30

The above are French feet, which are to the English as 114 to 107.

Jars has given the steel furnace, and the foundery furnace of England, but not the blast furnace.

17thly, Thus it appears, that a smelting furnace may be considered as divided into three parts; viz. the uppermost portion from the opening at top, downward to the narrow part of the boshes wherein the process of cementing goes on; that is, where the crude ore is gradually deprived of the oxygen, or substance that demetallizes it, by means of the carbon of the coals. Whether this be compleatly effected, depends first on the charge of the furnace; whether the coal, the iron-stone, and the blast, be each in due proportion to each other, so that no part of either shall escape the action of the other: secondly, on the degree of heat given to the charge, for this union of the carbon of the coal, with the oxygen of the iron, does not take place, but in a full red heat: thirdly, upon the size of the particles of ore, coal and limestone: and fourthly, upon the time the charge takes in descending from the top of the chimney to the bottom of the boshes, where the fusion or melting takes place; for, if it descend too quickly, the iron will not be sufficiently carbonated; part of it, in the form of ore, or oxyd, will be turned into glass with the slag, and the iron in the hearth will be imperfect *white* iron without a regular grain. On the contrary, if the proportion of coal be considerable, and the descent of the charge protracted, the iron will be *smooth-faced pig;* carburetted or supersaturated with carbon; it will be extremely fusible, more so than cast steel, which, in many properties, it greatly resembles; and a substance like plumbago or black lead, called kish, will float on its surface. This kind of pig, however, is very valuable, being used for castings of all kinds: where the coal, the heat, and the stone, have been in due proportion, the iron will be saturated with carbon, or nearly, so as to be metallic throughout. This is *forge pig;* a kind of iron uni-

formly preferred for tough and heavy work. Hence, this last or *forge pig*, is *carbonated* iron, wherein the charcoal has nearly abstracted the whole of the oxygen: *smooth faced pig* is *carburetted* iron, where the charcoal has superabundantly combined with the iron: the *white* and the *mottled* iron, is imperfectly and irregularly carbonated, and is least valuable.

The other parts of the furnace, are, from the boshes to the entrance of the blast, in which is to be considered whether the width and slope, will admit of the required regular descent—from the bottom of the boshes to the entrance of the blast where the iron and slag is finally fused; concerning which the points of consideration are the quantity, the velocity, and the direction of the blast—and the hearth, in which the melted metal is deposited.

18thly, In addition to the observations as to the proportions of charge, I would observe that in England, a common charge by weight, is four of coak, three and one-third argillaceous iron ore, and one limestone. At a furnace in England producing good melting iron, of a quality between the highly carburetted dark grey iron, No. 1, and the imperfectly white iron or forge pig carbonated—working an argillaceous iron ore containing 27 per cent. of iron—the furnace being 45 feet high, and twelve and a half feet diameter at the widest part—consuming 2500 cubic feet of air per minute, issuing from a tuyere of two and three fourth inches—the average charges of coak per *shift* (or 12 hours) are fifty of two and three-fourths hundred weight each, or nearly seven tons. The calcined or roasted ore for good melting iron, is of the same quantity, but for forge pig, or the least carbonated variety, 6 of coak to 7 of ore: the unburnt limestone is as 4 to 11 of ore. This furnace with such a daily charge produces 40 tons of metal per week.

A wood charcoal furnace requires somewhat less lime

than a coak furnace: and rich ore requires less than poor ore. The rich Lancashire ore of England worked with wood charcoal does not require more than one-fifteenth, or even one-twentieth of limestone: for as the ore abounds in metal, it contains a less quantity of earths that require to be fluxed.

As to the charges in this country, where charcoal and not coak is used, they vary considerably, but I do not find that the variation sufficiently depends upon principle. I have already stated a common charge.

According to the report of Mess. Dangenoux and Wendell on the iron works of Styria and Carinthia, 1 Jars 58, the coal measure at Eisenhartz, is three feet diameter at the top, one and a half foot at the bottom, and two feet deep.

The ore measure is 26 inches high, 21 inches top diameter, and 12 inches in the bottom. The charge is 2 measures of charcoal to one of ore.

At Vordenburg, the charge is 3 measures of charcoal, each measure being 30 inches deep, by 30 inches top diameter, and 18 inches bottom diameter, to one measure of ore, the measure being 18 inches square and 17 inches deep. All this however, as well as the proportion of flux, is of no consequence to the reader, and gives no information unless he knew the quality of the iron-stone. In many parts of Germany as I find by perusing the numerous accounts given by Jars, they make use of *waacken* as a flux. What Mr. Pott in his Lithogeognosie meant by waacken, I know not; it is impossible not to regret that a work in other respects so excellent should be rendered useless by the want of an accurate mineralogical language. The present waacken of the Germans, is an argillo-siliceous stone, consisting of nearly equal parts of the 2 earths. Hence the ores to which it is used, must be those wherein the particles of iron are enveloped in calcareous or limestone earth.

The toughest iron and that which requires most fuel, is from the siliceous ores; next to that the argillaceous; the most fusible and least tough iron is generally from calcareous iron-stones. All these I apprehend may be qualified by a due mixture with each other.

[*To be concluded in next number.*]

The next number will finish the article *Iron* and also *Steel.* I wish I could have made the preceding papers more popular and less chemical, but I could not. The time is at hand when young iron masters will find it necessary to become acquainted with chemistry; to such, the present essay will furnish abundant matter for reflection. It is not intended for the iron masters of the present day; for men of great industry, great experience, and generally of great wealth honourably acquired. Such men need no instruction, and I am not competent to give it if they did.

The other branches of manufacture, I shall treat in the same way, more or less at length as my materials induce me.

Wilkesbarre, March 16th, 1813.

Dear Sir,

HAVING observed by my last number of the Emporium of Arts and Sciences, that you had undertaken the editorship of that work, I send inclosed a copy of manuscript directions, in my possession, by an English manufacturer, for making bleaching liquor for the use of papermakers. I have preferred giving you an exact copy of it and the draught, to making any alterations in the style or drawing. Your knowledge of the subject will enable you to make the necessary corrections in both.

As the method of bleaching, by means of the oxygenated muriatic acid is, I believe, not known or in use in our paper-mills, it may be useful to the profession here to be informed, of the mode and process of conducting in Europe that part of their business.

I should be very happy to hear from you occasionally, and am,

Dear Sir,

Very respectfully your obedient servant,

Professor Cooper, Carlisle. JASP. CIST

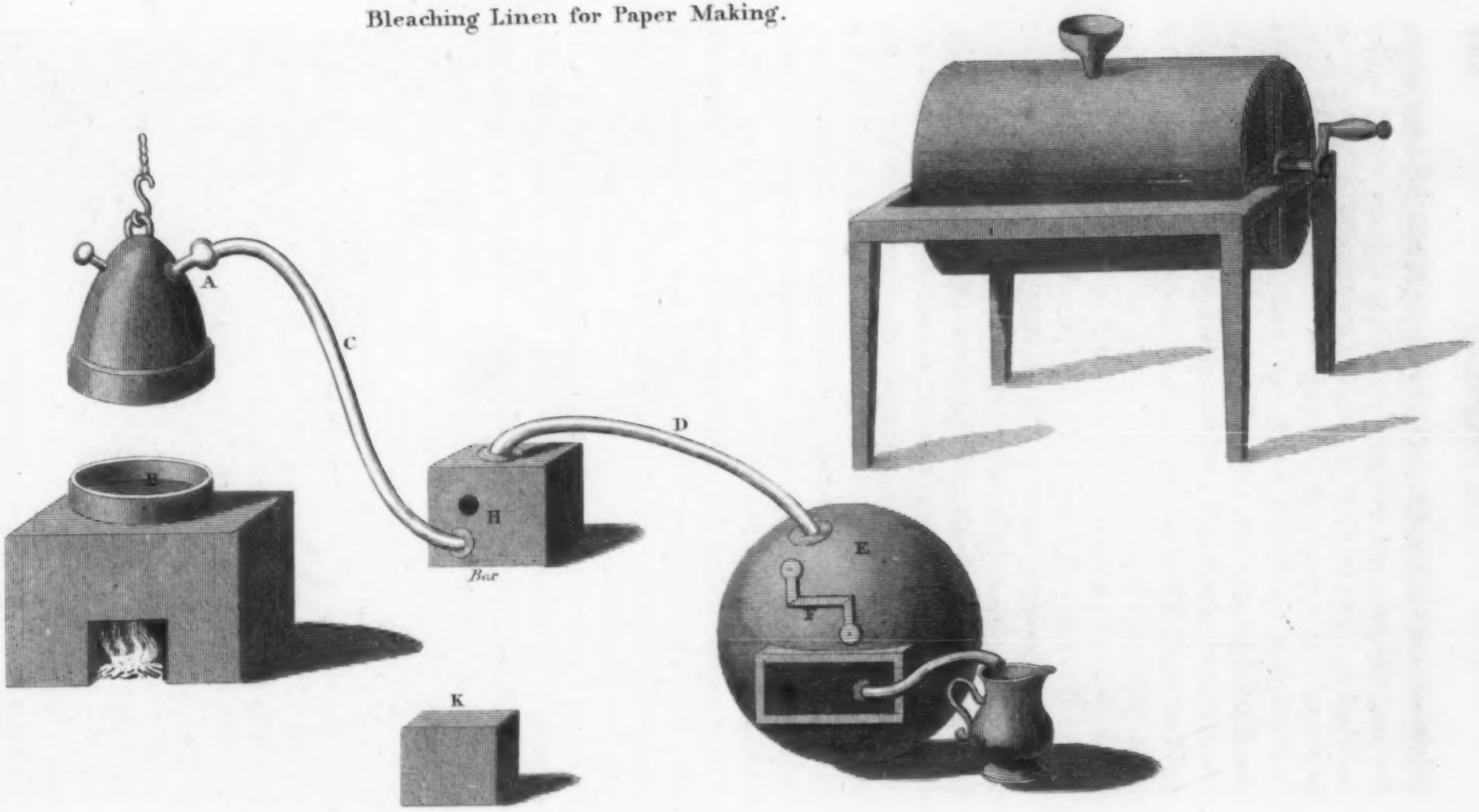
Directions for making 225 gallons of liquor for whitening stuff for papermakers.

First put into the still 21 gallons of salt brine, as strong as can be made, which may be known by putting in salt until some of it remains unmelted, then put into a box 45lbs, of the best salt, likewise 90lbs. of the best ground and powdered manganese, mix them very well until all appears as manganese, then put that mixture into the still, put on the head of the still, first stirring or blending it with a shovel until it is in motion, then have 126lbs. of the best vitriol in 6 jugs ready, put some vitriol into the tundish, first putting in the service pipe and luting it with clay as you see in the plan, then let in the vitriol gradually until you hear the jug on the reservoirs blab, then stop the vitriol, which must be done by a small iron rod made for that purpose to fit it, so let in your vitriol by degrees until all is in, which must not be less time than four hours at least, then 30 minutes after being in, light the fire and keep it very moderate for 10 or 12 hours, then you may keep the fire something stronger for the remainder of the time until the operation is finished, which will be 24 or 25 hours from the first putting in of the vitriol, then stop the ear pipe of the lid and let it stand 14 hours at least before you draw it off for use.

N. B. When the vitriol is all in, take out your tundish and have a ball of clay for luting the place it stood in; first of all, fill your reservoir with clear water to within 7 inches of the top of the consolidating lid—then put into the reservoir 50lbs of the best hot lime, finely sifted—agitate the reservoirs for 15 minutes, then put on your lid and fix your bubbling jug as you see in the plan; let the agitator be kept turning during the whole process, especially when the vitriol is going in; after you draw off your liquor in bottles, what remains in the reservoir of lime and liquor put it in a hogshead and fill it with water, stir it and let it stand until the next work, by putting it in the reservoir that you may have no loss; the same is used in what remains in the still of the old lees, let it be put in a vessel or cistern which stands contiguous to the still, and is also lined with sheet-lead; always used it will be a saving, as it answers better than the first by keeping it up to the 21 gallons with brine as directed; the saving is this, viz. that instead of 90lbs. manganese 74lbs. will be sufficient and 34lbs. salt instead of 45.

N. B. You are to take the greatest care not to let any of the manganese touch the reservoir, as the least particle of it would spoil the whole process.

Bleaching Linen for Paper Making.



W. Strickland del.

C. Tiebout sc.

If you have a mind to make liquor for bleaching linen cloth, let your liquor in the reservoir be 5 or 6 degrees strong of the hydrometer glass by pearl or potash, and the rest of the process as before; be sure to wash the reservoir very clean from lime, and be careful of your luting for fear of smell; the head of the still and lid of the reservoir is luted with water as you see in the plan. If you make it for linen, have the opinion of some man conversant in bleaching; if the glasses can be got, I will write the use of them. (See the plate.)

A The cap of the still.

B The body of ditto, which, as you see, stands 7 or 8 inches above the surface. The cap is in the form of a hive, entirely hollow, with the tundishes solddered, as you see, one for the use of charging the still with the vitriol, and the other takes off the inflammable air, which is C, then it enters the intermediate box, through which it passes through the pipe D, and enters the vessel by the reservoir, which is E. The pipe stands about 11 or 12 inches above the surface, 1 inch bore, but does not dip in the reservoir; it drops its strength in its reservoir, which the motion of the wheel circulates the body; the wheel or windlass, is the letter F, which is only the handle and a boy continually turning it during the whole process; ×┐ the wheel is in this form, with the arms the full diameter of the vessel; the intermediate box, as you see: the pipes or tubes stand 12 inches at the top, I mean from the horizontal of the top of the vessel. The centrepipe, which is H, dips in the water which is in the intermediate box and has two nostrils which give air, although being under water; the intermediate box has always 4 inches of water, which is put in every time the still is charged, and has a cock at the bottom to empty it occasionally; there is also the consolidate vessel, which is G, it stands about 7 inches high, but made fast to the top of the reservoir. The consolidate vessel is as thus: it has a lid, and on the lid is made fast a pipe which dips in the water 1 inch; the lid is taken off to put the lime-water in: also there is another pipe which stands about 3 inches on the top, and in that pipe fits a tube which dips in the pitcher as you see in the draught; the lid of the consolidating vessel fits in a cavity the same as the cap of the still, and the cavity is filled with water to keep it staunch; also there is a cock at the bottom of the reservoir to rack off the liquor, and another at the bottom to cleanse it out. The letter K is the vessel which the old lees are thrown into as before mentioned. As to the proportions of

the vessels I shall be very exact—the depth of the still is 2 feet 5 inches; the diameter 2 feet 3 inches; the cavity where the lid fits is 13 inches deep; the proportions of the intermediate vessel are 16 inches long, 12 inches broad, and 11 high; the reservoir is in depth 20 inches, diameter 4 feet 8 inches; the consolidating vessel which dips in the water is 14 inches square, 7 inches high at the top, and the lid has two handles to take it off. When you are going to put in the lime water, the cap of the still is elevated by a pully, which at the top of D° you see a hook made fast to D° for the same purpose, to put it on and take it off without any farther trouble. The still is laid in a metal boiler, and underneath the still is 4 inches of sand, but the body is a cavity all round to the top which is inclosed with brick work; the whole apparatus is lead. N. B. The reservoir is also lined with lead, as also the cistern which the old lees is thrown into. The reservoir is a wooden vessel, and, as I said before, lined with sheet lead. J. K.

REMARKS.

I am obliged to Mr. Cist for this communication, which bears the marks, tho' rough, of practical experience. But the proportions of the materials are not accurately adjusted. Twenty one gallons of saturated salt brine will not contain quite 60lbs. of salt, for 16 ounces or a pint of water, will not quite dissolve 6 ounces of salt. Hence the proportions here, are salt 105lb. manganese 90lb. oil of vitriol 126lb. water 160lb. But the best proportions are, by weight, salt 3 parts, manganese 3 parts, oil of vitriol of commerce (weighing 29 1-2 ounces to the wine pint) 6 parts, water 12 parts. So that to 112lb. of salt, there should have been about 50lb. manganese, and 80lb. oil of vitriol. These are the common proportions of the bleachers in Manchester. The receipt of Mr. Cist's correspondent is therefore wasteful in the dearest of the articles. If there should be a little less oil of vitriol, nothing is wasted but the salt, which, in this country, is of little consequence comparatively.

There have been two or three patents for bleaching paper in England. I know not how they succeeded. I shall have occasion to detail what I know on the subject of bleaching generally in a future paper. But as the present communication is entitled to an insertion, and the subject is before me, I shall give, for the present, the following process, which I am firmly persuaded is of much more importance than any thing that has hitherto been published on the subject. It has been already published in Dr.

Mease's edition of the Encyclopœdia, a very useful work, but containing much that may be thrown out, and wanting much that might be usefully added. I wish the Doctor would re-edit that book.

In the year 1790, a Frenchman came to Manchester to propose a new discovery in bleaching. A meeting was called, but the information he thought fit to give, was not of consequence enough to entitle him to attention. Mr. Thomas Henry, (the father of Dr. W. Henry, the chemist) myself, and Mr. C. Taylor, (afterwards secretary to the Adelphi Society of Arts) agreed that this was meant to be Berthollet's application of Scheele's discovery of the dephlogisticated marine acid (oxymuriatic acid.) We set to work, and made a quantity of the acid, and bleached with it several specimens of calico; imperfectly, because they required the cleansing of alkaline lixivia. During our experiments, it occurred to me, that as manganese was dirty, frequently impure, and frequently given out carbonic acid when treated with oil of vitriol, and that the residuum was not convertible to any known use, we had better employ minium or red lead, which I knew to contain 12 or 14 per cent of pure air.

It succeeded perfectly; and the vitriolated lead which formed the residuum, might be reduced to lead again. In hastily and carefully combining the vapour of this very pungent and unpleasant acid, by a strong bottle, well corked, it occurred to a friend of mine, Mr. Baker, a manufacturer of oil of vitriol, that the acid in question might be at once made without distillation in a vessel sufficiently strong. He tried it at home in a strong decanter, and succeeded. I embarked with him in reducing this discovery to practice, and until I came to this country, used it with perfect success on from 800 to 1200 pieces of calico weekly. The process was never published in England; I gave it to Dr. Mease, and nobody has noticed it. I give it again, that it may be more extensively known.

The plate accompanying the paper communicated by Mr. Cist, contains also a view of one of the machines used by Mr. Baker and myself, to make the oxymuriatic acid in.

The method of making this acid for bleaching, commonly used in Manchester and elsewhere, is by adding to 3 parts, by weight of manganese, 8 parts of common salt and 6 parts of oil of vitriol, and 12 of water....These are distilled together, and the products received in barrels of water, arranged in the manner of WOLFE's appara-

tus by tubes communicating from the retort to the first barrel, and from the first to a second. Sometimes the water is only impregnated with the acid, sometimes it is made to saturate lime or pearl ash. This process cannot be used with economy: the trouble and expence of retorts, and the attendance on the fire renders it far too complicated. It has not yet, and never will answer for goods in general. Where particular patterns are suddenly wanted for the market it may pay.

The writer of this article attended for three years continually to the bleaching of cotton goods of various kinds, to the amount of 800 pieces of callico per week, on the average of the year, by the following process. The goods underwent three boukings, as described before in this article, and two acid baths. The third was the oxygenated muriatic acid made as follows. In a building of one room on a bank and another over it, were placed on substantial frames or tressels, five wooden cylindrical machines four feet diameter by five feet long, the staves two and an half inches thick and well dovetailed. Into each of these, twice a day, through a funnel inserted in a two inch augur hole and let through the floor of the upper room was poured 75lb. of salt and 25lb. of red lead. To this was added 40lb. of oil of vitriol, weighing twenty-nine and a half ounces to the wine pint.

The machine was then filled with water, the augur hole stopt with a plug and rag, and then turned round 20 or 30 times, and in 15 minutes the acid was made.....The vitriolic acid acts on the salt, and the marine acid thus produced acts on the red lead, which in a few minutes is deprived of its oxygen, and converted into vitriol of lead. The handle of each machine was fixed on the centre of one of the ends with two cross-bars.....The acid when made was let off on the pieces placed in covered wooden vessels in a room adjoining and below. It frequently occasioned a spitting of blood among the workmen who took out the pieces, but was never attended with any further deleterious effects; laudanum relieved the short phthisicky cough. One of these vessels full was allowed to 60 muslinets. No lead remained in the liquor, for vitriol of lead is insoluble.

This process may be imitated in a small way, by pouring into a *strong* vial with a glass stopper, about an ounce of spirits of salt on a tea-spoonful of red-lead; stop the vial, heat is generated, the lead turns white and a very strong oxygenated acid is produced in a minute's time. But this acid will contain a little lead, while the acid made with vitriol and salt contains scarcely any. This acid has

lately been recommended by *Guyton Morveau*, as an effectual destroyer of putrid exhalation.]

It is obvious, that after the pulp of coloured rags is well cleansed from impurities, and washed well, and the water let off, this liquor can be conveyed upon it, in a covered wooden cistern. The pulp must be stirred once or twice by means of a long wooden rake, and a hole made for the purpose in the cover. It should thus remain 12 hours; and then be well washed to carry off all the acid.

The effect of this acid may be tried thus: into a *strong* six ounce vial, put a tea-spoonful of red lead, and 2 tea-spoonfulls of spirits of salt, mixed with as much water—put a piece of printed calico inside the vial, and close it in, by means of the cork—shake the vial to make the ingredients mix, and in a quarter of an hour the colours will be discharged by the vapour, or nearly so. **T. C.**

FOREIGN COMMERCE.

THE following essay in substance and nearly in form was first pulished in the Northumberland and Sunbury Gazette, in June, 1799; a second edition in 1800. The facts therefore are confined to that period. I republish it now, in conformity to my promise at the beginning of this number, because I am persuaded that all the leading principles of this paper are sound; and because it is high time to bring the COMMERCIAL SYSTEM into full discussion. If we are to adopt it, let us understand it first.

The measures necessary for defence, have also altered my opinion as to the propriety of introducing home-manufacture, and establishing a navy. If any reliance could be placed on the political integrity of Great Britain, I would not put pen to paper toward the introduction of Manufactures. We should be prosperous and happy enough as an agricultural country; but I fear no such reliance is to be placed on any government swayed by the principles of mercantile policy, whether there or here. In this opinion, I am not singular.

I consider it as against the interest of a country, to give particular encouragement to any employment of capital whatever; not even to agricultural investments. The calculating foresight of individuals, actuated and guided by the light of interest, will dis-

cover much more surely than any government can, how and where capital and labour can be employed to the most profit: and as I regard the aggregate of the wealth of the citizens, to be synonymous, with the wealth of the nation, it can seldom be wise for the administrators of national concerns to interfere in this respect, either by encouragement or prohibition. For many still stronger reasons, Commerce, ever clamorous for protection, is never worth protecting. In proportion as any employment of capital calls for national assistance and protection, it deserves none. The very demand itself, amounts to demonstrative evidence that the investment is injudicious, and ought to be abandoned. But of all employments of capital, that which calls for navies to guard it, and hourly jeopardizes the peace of the nation, deserves the least.

We are now unfortunately reduced to such a situation, that a navy for the defence of our coast, and a standing army for the defence of our frontier, seem permanently necessary: for it will be madness, after the experience of the revolutionary war and the present war, to trust to raw undisciplined militia, suddenly called from the plowshare to the bayonet.

For this state of things, we are indebted to the COMMERCIAL SYSTEM; of which every hour and every event that passes, evinces to me the danger and the cost. What is the origin of the present war in which we are involved? First, Great Britain, in April 1806, by the paper blockade of the Ems and the Weser; and again in May 1806, by a similar blockade from the Elbe to Brest; then France, in retaliation, by the Berlin decree of November 1806; then Great Britain by her orders in council of March and November 1807; then France by the Milan decree of December 1807; then Great Britain by her blockade of Carthagena; and then France by her decree of Bayonne, depredated on our commerce, under principles of blockade, perfectly new to the law of nations. Not satisfied with these acts of injustice, the two belligerents played into each others hands, by means of the *license trade*, to annihilate the commerce of America, and allowed to each other, being mutually at war, that very commerce they refused to us, with whom they were at peace. Doubtless neither on the one side or the other of the powers at war, can this conduct be defended: but our course certainly was, to let our merchants know, that if it was worth their while to engage in a traffic liable to so many interruptions, they might; if not, they might let it alone; and the people at home must be content to dispense with luxuries, intro-

duced under so many difficulties and and dangers. Most assuredly such a trade was not worth protecting at the *expence of a war.*

Meantime, our merchants encouraged without scruple the employment of British seamen on board their ships, and carried on their commerce to a very great extent by means of British subjects. The trade of false protections, and the disgraceful practices accompanying it, was undisguised and notorious, in our seaports; and formed a worthy counterpart to the forgeries of American documents openly sold at London. Great Britain, under pretence of searching for her own subjects, impressed American seamen also, whenever it suited the interest or inclination of the naval commanders. Thus it was: *Iliacos intra muros, peccatur et extra.* This is manifestly a mercantile war in all hands. Every cause and reason assigned, every paper and manifesto published, is of a commercial complexion; and all the difficulties that at this moment stand in the way of settling it, arise as much from the conduct of our merchants at home, as of the British abroad. It is the mercantile interest and the commercial system, in both countries, that have tempted and driven their respective governments into this war.

The British in, my opinion, had a right to prohibit the non-accustomed trade: they had a right to complain that our merchants navigated with their seamen, whom they wanted for national defence. We also have great right to complain, that the British commanders impressed our seamen as well as their own; adding to a careless, disregard of justice, the irritating insolence of office. But it is an obvious reply on their side, that to the unavoidable difficulty of distinguishing between the two nations, our own conduct has superadded new ones, that might and ought to have been avoided. Before we claimed justice we should have done it; and prohibited our merchants from the employment of British seamen, 'ere we went to war in claim of our own. I see many obstacles to the adjustment of this unpleasant system in the first instance, and still more as to its permanence.

I say nothing of the right of *expatriation.* I hope the question will not be burthened with this discussion. Certainly it is not the law in any country of Europe that I know of. In this country, the question came under review in *Talbot v. Jansen*, *Murray v. the Charming Betsy*, and *M'Ilvaine v. Cox;* but it has received no decision except that of Chief Justice Elsworth, in the case of Capt. Isaac Williams, which completely negatives the right. I think this right may be well defended on general principles; nor need

any good government be afraid to admit it, subject to some reasonable modifications in the exercise. Nor ought the slavish doctrines of Story's case and Calvin's case, to settle the law of the present day. But as the law now stands with *us*, how can *we* obtrude the question?

For all these difficulties, we may thank the commercial system. This war may continue a dozen years for aught we know; and it is more than probable that our seaports will be bombarded. Is the commercial system worth this? will it remunerate us? It is now clear, that a navy, and a standing army, will both become permanently necessary; and I shall not be sorry to see the one and the other extended far enough for home defence, and no further. But the navy will not stop here; the mercantile interest, will urge with incessant perseverance, its increase, for defence, not of our sea coast at home, but of their vessels abroad: and then keep clear of wars if you can. At what expence their ships are defended they care not. They look to their own interest, and leave other people to do the same: and who can blame them?

The following is the first of a series of papers that I will occasionally dedicate to this most interesting subject, in which I shall insert such views of the question, as have occurred to me, since the following Essay was written. T. C.

Commercial Licences granted by the English Government.

In 1802	68	In 1807	2606
1803	836	1808	4910
1804	1,141	1809	15,226
1805	791	1810	18,356
1806	1,620	1811	7,602

POLITICAL ARITHMETIC.

The comparative value of the *Agricultural* and *Commercial* systems, begins now to be somewhat understood in Europe, among those who have turned their attention to political economy. But I suspect it is a new subject here. It is a very important one every where; and I sincerely hope, we shall endeavour to profit in this

country, by European experience. It is impossible to enter fully into the discussion within the bounds of a newspaper Essay; nor can the back country supply the necessary materials for it; but imperfect as this will be, I am fully satisfied that there is a class of readers, whose approbation I shall be proud of, who will peruse it with attention, and regard it with indulgence.

It seems determined in *America*, that we shall be a commercial country. Our navy, our army our loans, our increased taxes have arisen from our Commerce. This is cried up as the grand source of national wealth, and power, and prosperity. I, on the contrary, am firmly persuaded that until the home territory of a country be well cultivated and peopled—until manufactures founded on population, are in a state to require other markets to be sought, foreign commerce is a losing concern; an appropriation of capital, seldom expedient, frequently detrimental; that it has proved so, wherever agriculture has been thrown into the back ground to advance the commercial system; that to afford it support by prohibitions and bounties, or protection by engaging in wars on account of it, or manning navies for its defence, is equally unwise and unjust; that if it cannot be carried on without the fostering aid of government, it ought like every other losing scheme to be left to its own fate, without taxing the rest of the community and their posterity for its support. That foreign commerce is unnecessary as an investment of surplus wealth in this country, where there is so much land calling aloud for cultivation and capital, and so deplorably managed for want of these; that all the usual motives to foreign commerce, greatly fail in this country, which comprizing every climate, may be made to supply every variety of produce from its own industry.

1st. *Of the meaning of Commerce.* The barter or exchange of commodities between different persons is *Commerce*. If it be confined to the citizens of any country among themselves, it is called *internal commerce*, or the home trade; if between the citizens of one country and those of another, it is *external commerce*, or foreign trade; if by means of the citizens of one country bartering abroad the produce or manufactures not of their own, but of other countries, it is the *carrying trade*.

2dly. *Capital employed in the* HOME TRADE, *is more beneficial to the country than capital employed in the* FOREIGN TRADE, *or the carrying trade.* Suppose a merchant of New Orleans purchases $ 1000 worth of pork and whiskey from a Kentucky farmer,

and sells it to a Louisiana sugar planter for 1200 dollars worth of sugar, and exchanges that sugar for 1400 dollars worth of cotton and woollen manufactured at Rhode Island—here is a spur given, a stimulus to the industry of our own citizens in Kentucky, in Louisiana, and in Rhode Island, to the amount not of the merchant's gain upon his thousand dollars merely, but to the whole amount of the thousand dollars, all of which circulates, becomes invested and productive again at home; and three at least of our citizens are gainers by each other in the first instance. This is internal commerce or the home trade.

If a merchant of New Orleans, sends 1000 dollars worth of pork and whiskey to the Havanna and brings home $1000 worth of cigars, his capital is employed as much for the encouragement of Spanish as of American industry; such a man is just as valuable to the Spanish colonies as the American states, excepting so far as he expends his gains in the latter country. In the case now put, he is usefully, but not so usefully employed to this country, as in the former.

Suppose an American merchant employed in carrying produce of one of the French colonies to Great Britain, for which he receives in return cotton goods of Manchester. Such a merchant may reside in Philadelphia, and spend part of his gains there, but he is the agent of France and Great Britain; the capital employed to load his vessel stimulates the industry of the French planter and the English weaver; and it is accidental only, if the vessel itself that earns the freight, be American. The wages paid to the sailors, are expended abroad, and add to the wealth of other countries. This may be gainful to the merchant in times when freight is high, but the gain to the country he lives in, consists only in that part of his income that he spends there: and even that comes out of the pockets of home consumers. For if Mr. America purchases the coffee of Mons. St. Domingo, and then invests it in the sherry of Signor Spain, it is clear that he gives encouragement to St. Domingo and Spain: and if the wine of Spain be brought to America, he gains ultimately at the expense of the Americans alone. These objections do not apply to a coasting trade, where the carriers are employed by the home producers.

Hence, in the home trade, or internal commerce, the capital and the profit are both gain to the nation; they are both expended in stimulating and rewarding home industry; in promoting permanent and productive improvements at home.

In the foreign trade of exchange, the capital employed, is equally beneficial to the country where the merchant lives, and the

country to which he trades. His own country reaps the advantage of whatever he expends there of the income he acquires.

In the carrying trade, the merchant belongs to foreign countries; his own country is no further benefitted by his industry, than the expenditure he makes in it, of part of those gains, which the home consumer enables him to acquire.

3dly, *The capital employed in the home trade, circulates twice or thrice, while a capital employed in the foreign trade circulates but once.* Reflect upon the travels, if I may so call them, of a capital employed *at home.* 1st, It goes from the home merchant to the home producer; the farmer or manufacturer. 2dly, It is paid over with profit to the home merchant by the home consumer, and the circulation begins anew.

In the *foreign* trade, the capital goes, 1st, into the hands of the home producer, and thus far stimulates industry at home. 2dly, It is intrusted in the form of produce to the captain or supercargo, who, 3dly, delivers it to the foreign merchant, who, of course, demands a credit, equivalent to the time necessary for the return of his own capital into his hands in his own country. 4thly, The foreign merchant, for this purpose, entrusts it to the foreign purchaser or consumer; who, after some time, returns it, 5thly, into the hands of the foreign merchant; who again, 6thly, invests it with the foreign producer, the farmer or producer of his own country. 7thly, The foreign produce thus purchased, is entrusted, on board the ship; whence, 8thly, it gets into the hands of the home merchant; who sells it, 9thly, to the consumer; who, 10thly, after usual credit, returns it again in the last place to the home merchant.

Adam Smith, Herenschwand, and La Riviere, all agreeing in the general course, vary somewhat in their view of it, from that now given. But from every view taken of it, we may fairly conclude, that the same capital puts in force 2 or 3 times the industry at home when employed in the home trade, that it does when employed in the foreign trade.

4thly. *Comparative importance of the foreign trade and home trade in point of amount.* The country of all others most engaged in foreign trade, and generally cited as an example of riches and prosperity derived from this source, is Great Britain. Let us see what her foreign trade amounts to, compared with her internal commerce.

The war with France has now continued seven years. It be-

gan in 1793. In estimating the value of the foreign trade of Great Britain, and taking the amount of exports as the exponent of it, I shall confine myself to the year preceding the war. Because, the first year of the war evidently sank the amount near five millions sterling below the natural progressive standard; because, in time of war, there is no steady march of foreign trade; the exports involve much of hazardous speculation. Because the custom-house entries are swelled by the amount of exports, consisting of articles consumed in the war itself, and purchased by government for the use of armies and navies; and these entries are gravely brought forward as evidences of the great increase of trade and national prosperity!

I know the objections to the accuracy of custom-house entries, and their official compared to their real value; but they are the best evidence we have; and an error of two or three millions, will make no difference in the present reasoning.

I say then, that the gross amount of the exports of Great Britain previous to the year 1794, *when the nation was fully embarked in the war, never reached* 25 *millions sterling.*

Year.	*Gross amount of export.*	*Balance of trade.*	*Nett customs paid into the exchequer.*	
1792	24,905,200	5,776,618	4,027,230	Upon export
1793	20,390,180	1 542,154	3,978,645	and import.

I state it also, as a calculation well known and generally received in that country, that a merchant's and manufacturer's clear profit is 12 1-2 per cent on his capital, which, on 25 millions, will be 3,125,000*l.* This is paid by the foreign consumer, and the nation gains it. The trade of Ireland that year may be calculated at 3 1-2 millions, on which the gain will be 437,500*l.* So that in the most prosperous year of peace, the clear profit on the whole foreign commerce of Great Britain and Ireland, can hardly be taken at more than 3 1-2 millions sterling!

Let us now see what is the amount of the home trade, or internal commerce; this consists of the amount of agricultural produce, and the amount of manufacturing produce: including woods, minerals and fisheries.

It appears from the first report of the select committee on the waste lands, ordered to be printed December 23, 1795, that there are in Great Britain 73,285,628 acres, of which 51,178,627 are cultivated, and 22,107,000 are uncultivated. The cultivated lands of Great Britain produce a wheat crop of certainly not less than

18 bushels an acre: Arthur Young, a competent judge, states it at 24 for England. Wheat, however, does not, or ought not, to occupy more than one year in four; the others being appropriated to potatoes, rye, barley, oats, beans, peas, turnips, cabbages, carrots, or grasses. If the average crop therefore be taken at 10 bushels, it will be somewhat below the amount. The average price of wheat for December, 1792, according to Young's annals of agriculture, was 6*s*. 1*d*. This will make the average produce of the agriculture of the kingdom 3*l*. sterling per acre; a calculation sufficiently low, when it is considered, that this produce must maintain the farmer and his family, his labourers, his horses: it must pay the rent of the land, the tythe, the parliamentary taxes, and the poor tax. At this rate the gross amount of the annual agricultural produce of Great Britain, is 150 millions sterling: exclusive of mines, fisheries, and woods. As the import of grain is very great, the whole of this amount belongs to home consumption.

The calculations of the statists of that country, are, that the manufacturers and mechanics equal in number the labourers in agriculture. It is not therefore too much to assign to the manufacturing and mechanic labour for the home trade of Great Britain, one third part of the agricultural value, or 50 millions.

Great Britain contains 11 millions of people, Ireland more than three. If the internal trade of Ireland be taken at one tenth of Great Britain, then will the annual circulating wealth of the internal commerce of the British empire, be not less than 220 millions sterling.

This subject may be otherwise considered. The actual expenditure of the rich and poor taken on average of Great Britain, cannot be less than one shilling sterling per head per day, for food, fuel, furniture, and clothing. It is probably much more. But 11 millions of people at 1*s*. st. per head per day, will amount to 200 millions and 3-4: a coincidence of calculation, that gives weight to the principles on which it is founded.

If the gross amount of the foreign trade of Great Britain then be 25 millions, at the same time when the gross amount of the home trade is 200 millions, who can be mad enough to attribute the power and prosperity of that Kingdom to the foreign trade?

Again. The taxes of that country must be bore partly by the foreign, partly by the home trade. Last year (1798) the minister demanded supplies to the amount of 35 millions: the gross receipt of the customs was 5 1-2 millions including export and im-

port. What capital was it that bore the rest? But in fact, the foreign trade bore but about one half of this 5 1-2 millions, for it is the home consumer, not the foreign consumer, that pays the tax on import: that tax, is a burthen not on the foreign, but on the home trade. Of the 35 millions required therefore, the foreign trade of Great Britain did not supply three.

So in 1800, the Custom house produced about six and three-fourths millions. But the interest of the debt that year was *l.* 20,186,507 and the demands of supply for the army, the navy, the ordnance, the civil list, the miscellaneous services, the interest of the loan, &c. as much more. But if the foreign trade can furnish as in this case, but a sixth part of the supplies required, where does the rest come from? Is there any other source but the internal commerce of agricultural and manufactured produce? Take any year of the last half century, and you will find, that the foreign trade has borne but a very small part of the national burthens.

Where then is the great source of wealth, of that powerful and wealthy country? It is in her spirited agriculture: in 100 millions st. of farming-capital, permanently laid out in buildings, in fences, in roads, in canals, in machines. In 50 millions more annually expended in manures, in repairs, in exuberant cultivation. Here is the secret of 24 bushels in England, 16 in France, and 10 in this country. And so in her manufactures; the intense activity and energy, which the high price of living requires from every body in England; the wonderful skill acquired by the division of labour; the great superiority of task work over day labour; and the immense capital under the direction of profound knowledge in the manufacturing machinery of that country, enable her inhabitants to bear the enormous expence of her government.

In France under the old Regime, if a man possest 5000 louis, he bought a marquisate: in England a young man with 5000 guineas would enter as the junior partner of some house of repute. In France, a tradesman scorned to work for the Canaille, if he could help it: in England every tradesman consults the taste of the great mass of customers, the middle and the lower classes of society. In France, accumulated capital was spent; in England it is employed for the most part in begetting capital. In France, trade is disreputable; in England, all kinds of industry, are compatible with the acquirements of a scholar, and the polish of a gentleman.

By the report on the waste lands, 22 millions of acres appear to be uncultivated: of which upwards of 20 millions admit of cultiva-

tion. Suppose being cultivated, the produce per acre might be 5s. sterling. Then would the waste lands of that kingdom become a source of wealth to the nation beyond the profit of the whole foreign trade.

Next to Great Britain, France of all the great European powers has the largest proportion of foreign trade. France contains 131,722,711 acres: that is 130 millions of acres exclusive of roads, &c. The proportion of produce between England and France per acre is as 24 to 16. From the data furnished by A. Young in his tour to France, v. 1 p. 282, 341, et seq. I calculate the gross amount of the produce of lands in France at 30s. sterling per acre, or 200 millions; and as the manufactures of that country are greatly less valuable than those of England, I should not rate the whole amount of the home trade of that kingdom beyond 225 millions, (1792-3). There is no getting at accuracy in these matters; especially situated as I am; but luckily, the principles in question, do not need any thing more than a reasonable approximation to truth.

I have no modern facts as to the Commerce of France. M. Arnould in his Balance du Commerce, states the average exports of France from 1784 to 1788, at 354,423,000 livres; or about fifteen and a half millions sterling; the average for the same period in Great Britain would give sixteen and a half millions. Can the power and prosperity of either country at that period, be ascribed to the merchant's gain of twelve and a half or 15 per cent. on these insignificant sums? ought we not rather to look for it in the excess of industry over expenditure, in the 200 or 225 millions of home trade? Especially when it is considered that immediately previous to the war of 1793, the taxes of Great Britain (exclusive of Tythe, Road, and Poor Tax) amounted to near 20, and of France to 25 millions?

We are surprized at the exertions of Great Britain, and her full equality in power to France, when the population and the territory of the latter country is so much greater. But we shall wonder no longer, when we consider that under the bold expenditure of farming capital in Great Britain, the quantity of agricultural produce of both countries is nearly equal, and the manufacturing produce of the latter country, much greater. Wealth arises from land, and labour, and capital, being employed productively, instead of land being kept waste, labour unemployed, and capital dissipated in fruitless luxury.

But let us turn our eyes to our own country. Our population amounts now (1800) to about five millions. Suppose 5 acres per

head cleared: a proportion not too large, for I know by repeated calculation, that it takes at least three acres to supply the food and drink of a labouring man here, as labourers usually live. Then will there be 25 millions of acres in cultivation, producing an average annual value of 5 dollars per acre, or 28 millions sterling. The produce of timber, lumber, fuel, cabinet-wood, game, &c.—of the fisheries of our rivers and streams—of home manufacture of every description, may be reasonably computed at one fourth more; making a total of 35 millions sterling, for the home produce of the American states.

The last report of the gross amount of foreign trade (our exports) was 61 millions of dollars, of which 33 millions was the value of produce of foreign nations. Our own foreign trade then, amounted to 28 millions of dollars, or about six and one-fourth millions sterling; while the gross amount of internal produce is nearly six times that sum.

Such was the state of things about 1798, 1799.

Hence it appears, that whether we look at England, France, or America, the gross amount of the home trade is prodigiously beyond that of the foreign trade; which has no pretensions to be regarded as the great source of national wealth.

5thly, *The lands of America stand particularly in need of capital.* When I state this, I am not an advocate for colonizing the wilderness two thousand miles from our sea-board. Our frontier is already extended beyond all reasonable bounds. But the space of territory we might prudently populate, is not half peopled* or near it. Of the populated part, the lands are not half cleared; of the cleared lands under cultivation, not one acre in a hundred is half cultivated. I am afraid I over calculate, when I rate an average wheat produce at 10 bushels, most certainly not half the average of England. 1 Young's French Tour, 343, 431, gives the details that shew the superior produce of England over France, to be owing to the greater agricultural capital of the former nation. Under these circumstances, it is not prudent to foster, and encourage the investment of capital in foreign trade.

6thly, *The capital of the foreign trade, is more precarious than that of the home trade.* Precarious from the hazard of storms, the hazard of war, the hazard of failure of a foreign debtor, living at a great distance and under foreign jurisdiction. The very idea

* New England, on 72,000 square miles, contained 1 1-4 millions of people in 1800: not 18 to a mile.

of insurance companies is commercial. Hence, if the same capital could be employed to equal profit, national and individual at home, it were better so employed than abroad.

Suppose a ship lost by storm, by depredation upon our commerce, by unjust adjudication, the value is gone from us, it is annihilated. It is true the merchant may lose nothing—he can generally lay his losses on the consumer. The price of insurance is part of the price of the commodities insured. Suppose the value of a cargo laid out on a plantation, in building, fencing, making roads, manuring, &c. a storm may destroy the crop, as well as the ship, but the produce of the year only is lost: the capital still remains, permanent and productive.

7thly, *The merchant, and all the people directly employed by him, rank among the unproductive classes of society.* The farmer, the wood-cutter, the miner, the manufacturer, the fisherman, employs his capital and labour in producing substantial riches, some commodity of value. I know this has been doubted as to the manufacturer; but it is, in my opinion, absurd to say that a millwright, a saw-maker, an engineer, and all who convert raw materials into labour-saving articles, are not of the productive class; and eminently so. This *may* be occasionally the case with the persons in question, but we are not talking of exceptions to a general rule, but of the rule itself.

The merchant, the agent, the factor, the retailer, the clerk, the captain, the seamen, are employed in arranging, assorting, dividing, transporting what has been already produced by the capital and labour of others. If produce be (as it clearly is) the real, the only riches of a country, we ought to aim at encreasing it, and encourage (if the system of encouragement *be* adopted at all) the employments that are productive, rather than those that are not so. All these people are usefully employed under the system of commerce; but it forms a drawback to that system, that so many persons are unproductively employed. I am aware of the objection, where will you find a market? There is never want of a market in a new settlement: you can *make* your market, by manufacturing a great part of what you buy. When provisions become a drug, manufacture starts up, and population abounds. This is the most desirable and most permanent order of things, because nature herself has pointed it out.

8thly, *Mercantile success tempts to imprudent expenditure and speculation.* It is no slight objection, that, while by the peaceful

labours of agriculture, gains can be made but slowly, gradually, and by the regular exertions of habitual, wholesome industry—the commercial speculator, often gets rich by accident, by imprudent and unfair venturing, by sudden exertions. Wealth thus suddenly obtained, is, in many respects, detrimental to the community. It operates as a lottery: it tempts capital into trade beyond prudent bounds: it entices to unjustifiable boldness: it too often introduces ostentatious luxury, not warranted by the sober dictates of moderate and regular gains.

9thly. *The merchant is of no country.* That is, he is not necessarily attached to any. His connections are as much out of his native country, as in it; he has frequently inducements to sojourn abroad: the domicil of nativity, and the mercantile domicil, are so often different, that the distinction with the privileges belonging to it, are recognized and settled in the laws of all commercial countries. His property is moveable, transportable; that is his country, where his interest calls him, where his means of gain have located his investments. Where the treasure is, there will the heart be also.

Nor is it to be expected that mercantile speculations, will be voluntarily regulated by national expedience. It is the merchant's business to attend to his own concerns; let the governors of the nation attend to the national concerns. Of what consequence is it to the merchant, at what expense the commerce of his country is supported? the nation, the home consumer, pays for all. Increased expences are always and reasonably laid on the price of the commodity: the merchant therefore cares little about them, provided they are common to the body of merchants. It is his interest to magnify the great importance of foreign commerce; to obtain protection for it though at ten times its value to the nation; to engage government on his side; and this unfortunately he is generally enabled to do, by his importance to revenue, to loans, to banks, to finance operations; men in power and merchants are always allies. However clear sighted as an individual, the *statesman*, sees nothing but revenue. The merchant sees and steadily pursues his own interest. Is not this too natural to be blameable?

Moreover, the merchant's occupation is always liable, not only to the temptation of illicit pursuit, but to the jealousies of foreign mercantile interests, to quarrels and controversies involving national feeling. Let the reader reflect on the cover our professed neu-

trality has afforded, during these seven years of continental war (1793 to 1800) for illicit trade, for jealousy, for complaint, for attack, for real and for pretended retaliation.

From all these objections, the home trade is free. The home trader is fixed; he has his all at stake in the country he lives in; he can have no interest out of it; he can be counted upon; foreign interests, and foreign governments have no hold on him; he has neither the temptation, the means, the opportunity, or the inclination of doing national mischief, or giving cause for national offence, or giving rise to national quarrels; in the common course of things, and necessarily, his interests and his country's interests are coincident; his gains are his country's gains; whatever capital he employs, stimulates not foreign but home industry; it is employed in, and upon, and for, his own nation and national territory; all his affections and associations are connected with home, and centre there.

10thly, *Commerce has never paid the interest of the expensive wars it has induced.* It is useless to examine this question by the example of many of the maritime countries of Europe. The inferences from British facts, will suffice: *ex uno disce omnes.*

Sir John Sinclair states the commercial wars of George II. and George III. (2 Hist. of the public revenue, 99) as follows: war of 1739, 46,418,689*l.*: war of 1756, 111,271,996*l.*: American war, 139,171,876*l.*: Russian and Spanish armaments, 2,311,385*l.*: Total,299, 173,946, or, in round numbers, 300 millions sterling.

Government has borrowed at rates from 4 1-2 to 5 1-2 per cent. Now I should be glad, if any advocate of the commercial system could point out to me, when Great Britain ever made, or when she is likely to make 15 millions' profit on a year's export!

But; the fifteen million annual taxes thus permanently saddled on the country in support of the commercial system, is not all. On the 20th of Dec. 1792, parliament granted as supplies for the navy, for 1793, somewhat above 4 millions sterling. A sum that has annually encreased ever since that time: but I confine myself to the peace establishment. I well know that a navy is necessary to Great Britain as a means of defence, but not such a navy: Her navy is not employed in home defence, nor a fourth part of it. The East Indies, the West Indies, the Mediterranean, the whole world dotted over with her commercial colonies, call for it. I am greatly within bounds, if I state, that two of the four millions is to be regularly charged to her commercial system. Look into the mis-

cellaneous services for the same year, and you may pick out about half a million more that goes to the debit of the same account. Admirable system! which purchases an annuity of 3 millions and a half at the certain expence of an annuity of 17 millions, and the probable expence of as much more. For war and commerce are steady companions.*

I say nothing as to the East India Company. That concern is insolvent.

Much indeed of all this expence has been owing to the system of colonization: but colonization is the immediate offspring of foreign commerce, whose life and soul on the modern system is monopoly. I am decidedly convinced that colonies are millstones round the neck of every European nation that has fostered them; the very worst part of the system of Commerce. I am sorry to say, that, much of the calculations which demonstrate this, are applicable to the conduct of the United States, in their mode of peopling the wilderness of America. The frontier is extended till the strength of the country is weakened. I almost doubt if we are at this moment so competent to meet hostilities, as at the beginning of the revolutionary war.

11thly, *The modern system of foreign commerce, is the most productive source of human misery.*

Almost all modern wars are *purely* commercial: *none* of them are free from commercial motives and considerations. Would to God the means existed of, easily, cheaply, and surely destroying a ship of war! The quarrels of nations are no longer local. Sting the pride, or touch the interest of England or France, and devastation extends at once to every quarter of the globe!

It was not better two centuries ago, when the colonizing and commercial system *began* to rage. Turn your eyes to the conduct of the Spanish in South America—the Portuguese in Africa—the British and Dutch in the East Indies—to the slave trade, that disgrace of humanity, and say if this position requires farther proof.—

12thly, *The most flourishing, populous, and best cultivated parts of Europe, are not maritime or commercial.* I except Holland; that is not a country but a city of merchants; driven into the sys-

* This is not much unlike the infatuation of Great Britain as to the woollen trade. It seems to me *proved*, that the whole commercial profit of that avaricious manufacture, has been taken from the pocket of the English farmer, who has been prohibited from exporting his wool. But the farmer is an animal, whom the merchant and the manufacturer can shear with impunity.

tem of foreign commerce and the carrying trade by their maritime situation; they had no other resource, for they possess comparatively no territory.

I select the following from Jameson's Political Geopraphy, which I prefer to Zimmerman's. The first table contains the maritime and commercial nations, with the inhabitants upon a square mile. The second table contains the states which enjoy little or no foreign commerce, with the inhabitants on a square mile in those states.

Table First.		*Second Table.*	
Great Britain and Ireland,	111	The whole of Germany,	135
Great Britain,	119*	Palatinate of the Rhine with Bavaria,	134
England and Wales,	150†		
Ireland,	109	Electorate of Saxony,	150
Scotland,	59	French acquisition on the left bank of the Rhine,	200
France,	157‡		
Spain,	70	Piedmont,	240
Portugal,	72	The Milanese and Austrian Italy,	240§
Denmark,	13		
Sweden,	14	The Pope's State,	160
European Russia,	17	Republic of Venice,	193.

To which it will not be unfair to add the empire of China with no foreign trade, but permitting every nation on payment of duties to fetch away her Commodities, 333 per square mile. To say nothing of the inland country of India, equally populous, by the cultivation of the earth, and internal manufacture.¶

I may assert further, as a known fact to European travellers or readers of travels, that the public monuments of art and apparent wealth of the second table, exceed the first.

13thly, *The Commercial nations have uniformly fallen before the Agricultural nations.*

* Zimmerman.

† This is far too great, being calculated on a surface of 79,712 square miles, whereas the report of the Committee of waste lands, before quoted, make a surface of seventy-three and one-fourth millions of acres, or about 114,500 square miles, or about 106 to a square mile. There are in fact not so many. Distribute 11 millions of souls over 114,500 square miles. All the preceding calculations are therefore too high for the same reason.

‡ This is too high, being calculated on a surface of 157,924 square miles, whereas Neckar and Young allow 205,816 square miles to old France.

§ Young states the Milanese at 354 per square mile.

¶ Inland towns of 2 or 3 millions of people, have not been uncommon in India. Visapour, an inland town, contained at one time near a million of houses. See Captain Moore's narrative.

Antiently, Tyre, Sidon, Carthage, before the Macedonians and Romans: Athens subdued by Lacedæmon: Corinth, Syracuse, Alexandria, by the Romans: Byzantium, by the followers of Mahomet. Where are Venice, Geneva, the Hans Towns, Holland? In commercial nations, surplus wealth is mostly expended in articles of luxurious consumption, *quæ ipso usu consumuntur*, and yield no profit.

In agricultural countries, a far greater portion is spent in substantial improvements on estates; in luxuries perhaps, but in permanent and productive luxuries. Hence provisions are cheap, population thick; the raw materials of warfare easy to be found.

What then are we to conclude? Prohibit commerce? Refuse protection to our citizens engaged in lawful occupations? Are not our merchants as much entitled to defence as any other class? No. Prohibit nothing: but protect no speculation, no investment of capital at an expence beyond its national value.

If wars are necessarily attendant upon commerce, it is far wiser to dispense with it; and imitate the nations who have flourished without foreign trade. Those who want your commodities will fetch them away. If they will go to China for tea-cups, they will come to America for bread. But if your merchants *chuse* this mode of investing their capital, do not forbid them. Let them do it like other adventurers, at their own risk. While it is profitable, let them pursue it; but should the quarrels of other nations, render it unprofitable, do not bolster it up by the bounty of protection, at an expence of ten times its value, and at the hazard even of national existence. Foreign trade with peace is desirable, but not so if it be the parent of war.

All wars should be defensive wars, and those only: *pro aris et focis*, for our houses and homes. Can we call a war undertaken to protect a mercantile speculation 5000 miles off, a *defensive* war?

At any rate, sit down and count the cost. If the expence of fencing my garden lot against depredation, will exceed the value of the ground, and involve me in a law suit into the bargain, I had better let it remain uncultivated.

If any profession is to be fostered, let it be the tiller of the earth: the fountain-head of all wealth, of all power, and all prosperity. Improve your roads, clear your rivers, cut your canals, build your bridges, establish schools and colleges, facilitate intercourse, and diffuse knowledge of all kinds. No fear but if you raise produce and people, they will find their market, either at home or

abroad. It will soon be discovered, what articles are most wanted, what are most profitable, and these will be supplied. On this simple plan of *home defence*, wars may be avoided, for what nation would or could invade this? But on the system of foreign commerce, the misconduct of your own, or of foreign merchants, will forever make peace insecure. Even your honourable successes will be causes of jealousy to other nations whose councils are guided by mercantile policy, and the maxims of the counting house. On that system, wars, debts, taxes, and despotism will be inevitable.

T. C.

SUGAR FROM BEETS AND GRAPES.

I observe in some late numbers of the Moniteur, that to April 1812, (Monit. of 19th April of that year) two hundred and fourteen licenses had been taken out for the manufacture of sugar from beets in France; hence I presume it must be, not only a practicable, but, in that country, a profitable concern, or the tax would not be paid for the license.

Klaproth, who repeated Achard's experiments on this subject at Berlin, procured from 25 beet-roots, which, when topped and scraped, weighed 32 1-2lb. 19 3-4lb. of juice by expression. The squeezed residuum was boiled in water, and again pressed. The liquors added together were boiled to a syrup, strained and slowly evaporated. The raw sugar amounted to 2lb. and 12 ounces.

The king of Prussia, in the fall of 1799, appointed a committee to repeat these experiments. They did so. From 1500lb. of beet-root, they produced 398lb. of syrup; which yielded 57lb. of tolerably white powder sugar.

I mention this, not to recommend the substitution of beets for the sugar cane, though I hope we shall soon substitute Louisiana for the West Indies; but to suggest a query, whether the expressed juice of beets, would not be a profitable article to distill?

The French also, procure sugar from the syrup of grapes. (Appercus des resultats obtenus, &c.) "Practical view of the "results obtained from the syrup and conserve of grapes in France, "during the years 1810 and 1811, by M. Parmentier, published by "order of government—price 5 francs."

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BURNING GLASSES.

A remarkably large parabolic lens was recently purchased at Vienna, for the French government. It was made at Gratz, in Styria, by Rospine, a celebrated mechanist, for some alchemist. It was not cast, but softened by heat and bent over a parabolic mould. Several pieces were broken before he succeeded; so that it cost originally from 800 to 1200 guineas. It is three feet three inches in diameter, and of eight feet four inches focus; composed of 2 pieces of glass united together by an iron hoop so as to form a hollow vessel, capable of holding eighty or ninety quarts of spirits of wine. M. Jacquin, of Vienna, and several men of science, who witnessed the experiments, declared, that it burned a diamond in a few seconds, and fused platina in a few minutes. A button of platina weighing twenty-nine grains, was melted by it, and made in part to boil. The diameter of the focus does not appear to exceed four lines. It weighs 550lbs. avoirdupois. *London Pap.*

This seems to me to be an improvement in the manufacture of lenses.

Of burning glasses. I have examined the question concerning the burning glasses of Archimedes. It rests upon vague and second hand authority. Polybius says nothing of it: nor Livy, nor Plutarch. There is not authority sufficient for the story of the burning glasses of Proclus. Such feats may have been done; there is no clear testimony to warrant our assertion that they were done.

In modern times, the glasses of Villette, Tchirnhausen, Buffon, Trudaine, and Parker are well known. That of M. Trudaine made at the expence of 1000*l.* sterling and presented by him to the Academy of sciences was constructed somewhat on the principle of the above mentioned lens. Two concave glasses, joined by their edges so as to present a cavity of 4 feet diameter, filled with 140 French pints of spirit of wine. It was broken by accident soon after it was presented. In the glass above mentioned made at Vienna, the improvement seems to be, the bending the plane glasses by gradual heat, over the mould.

Parker's lens, made at the expence of 700*l.* sterling, was sold by him for less than prime cost, and carried out by Lord Macartney as a present to the emperor of China, to be placed among the toys of that childish court. This was clearly the best lens ever constructed; and it is a disgrace to the nation, that Mr. Parker

was obliged so to dispose of it; and that a philosophical instrument, the finest of the kind the world had yet seen, should have been so egregiously thrown away.

The blow pipe, supplied with hydrogen and oxygen gasses, affords a degree of heat nearly equal to the best burning glass.

Dr. Bollman, who has so ably discussed (but not exhausted) the question of banks and paper money, has succeeded in manufacturing Platina into bars, wire, spoons, and crucibles. I do not know his process, which he has a right to reserve for his own emolument. The common method is, to dissolve the platina in nitro-muriatic acid, to precipitate it with sal-ammoniac; to redissolve and reprecipitate this orange-coloured oxyd of platina; to put it when dry into a crucible without addition, unless, perhaps, of lamp black. It is exposed to a strong heat till it becomes agglutinated in a spongy mass. This spungy mass while strongly heated, is pressed down with as much force as the crucible will admit, and this is continued till the parts approximate. The mass is then taken out, and hammered gradually and gently, till it unites in an uniform mass, and is then rolled. This, I say, is the common method.

Dr. Bollman's platina, is of specific gravity 19,7 the same as gold. Mr. Cloud, of the mint, to whom we are indebted for much useful and curious knowledge on platina, and the methods of purifying it, has freed it from the iron, palladium, iridium, and rhodium, so that his specimen of *pure* platina, is upwards of 21 spec. grav. I give this notice with great satisfaction, in hopes, that Dr. Bollman may benefit by it, as well as the public. He is entitled so to do.

The same gentleman has also succeeded, in a small way, in purifying the pyroligneous acid, so as to make it a substitute for distilled vinegar: a manufacture, attended, as I hear, with great success in France. In England, the pyroligneous acid (the acid liquor poduced from wood by distillation) has long been applied in the large way, to the making of iron liquor, for the dyers and printers of London and Manchester.

CAST IRON.

It has been mentioned that cast-iron, when at a certain degree of heat, may be cut like a piece of wood, with a common saw. The discovery was announced in a letter from M. Duford, director of the iron-works at Montalaire, to M. D'Arcet, and published in the Annales de Chimie. This experiment was tried at Glasgow, on Monday se'nnight, with complete success, by a gentleman of the philosophical society there, who, in presence of the workmen belonging to an ironmonger, cut with the greatest ease, a bar of cast-iron, previously heated to a cherry red, with a common carpenter's saw, in the course of less than two minutes. The saw was not in the least injured by the operation.

NOTICE TO CORRESPONDENTS.

I have received a letter signed O. E. on turpike roads. The only reason why it is not published in the present number, is, because I wish to say something on the subject myself, in addition to O. E's paper, for which I thank him.

An accident has prevented my inserting the analysis of the limestones, transmitted to me by Judge Peters. I have to repeat the experiments in consequence of this. I will endeavour to insert them in the next number.

A correspondent of the Emporium enquires, whether and when it is intended to give papers on the dying of cotton. If I continue to conduct this Emporium, I shall endeavor to present the information I have collected, in a way as little desultory as possible. I know that the generality of readers, love to see a pamphlet that treats on twenty subjects at once; but as I really mean to make this, if I can, a collection worth preserving, I will not go on in that way, by which no connected information can be given. To make a medley of this kind, I have nothing to do but to mark with my pencil the essays I choose to pillage from British compilations, and give the books to the printer. I will not do this.

I propose to draw up regular, connected essays on manufacturing processes; composing, compiling, selecting, abridging, and arranging, in the best manner I am able. This trouble I might easily save myself by pursuing the common method, and make

the book in all probability more popular. But it would neither be useful to the public, nor creditable to myself.

Two thirds, or thereabout, of every number shall be devoted to essays on the manufactures connected with iron, steel, lead, copper, tin, silver, gold, and the other metals and semi-metals. I will then proceed to the subjects of bleaching, dying, and printing; the making of colours and of drugs; to brewing, distilling, and other subjects of manufacture, concerning which I have already made my collections. From one half to one third of each number shall be devoted to miscellaneous articles. Like other labourers in the same field, I shall depredate in all quarters, and borrow where I can; still, the work shall bear evident marks of my own labour upon it. T. C.

Alexander & Phillips, Printers, Carlisle.

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TO BE SOLD,

The following works by the Editor of the Emporium.

The opinion delivered by Judge Cooper on the effect of sentences in foreign Courts of Vice Admiralty.

The Institutes of Justinian, with notes.

Introductory Lecture to a course of Chemistry at Dickinson College, Carlisle, with an Appendix and Notes.